Testing Second Generation Yukawas at LHC

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(work in progress)

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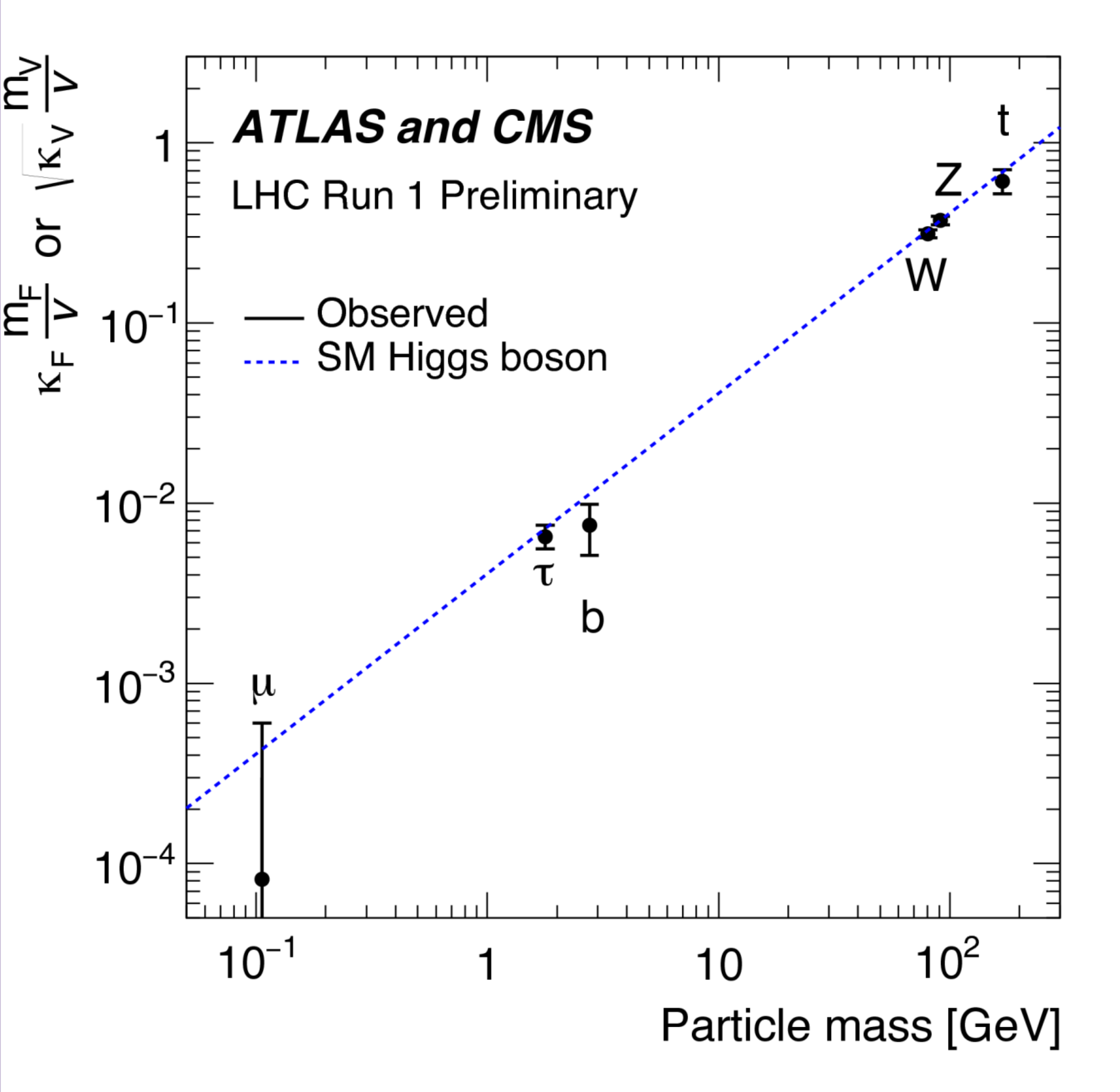
Motivation

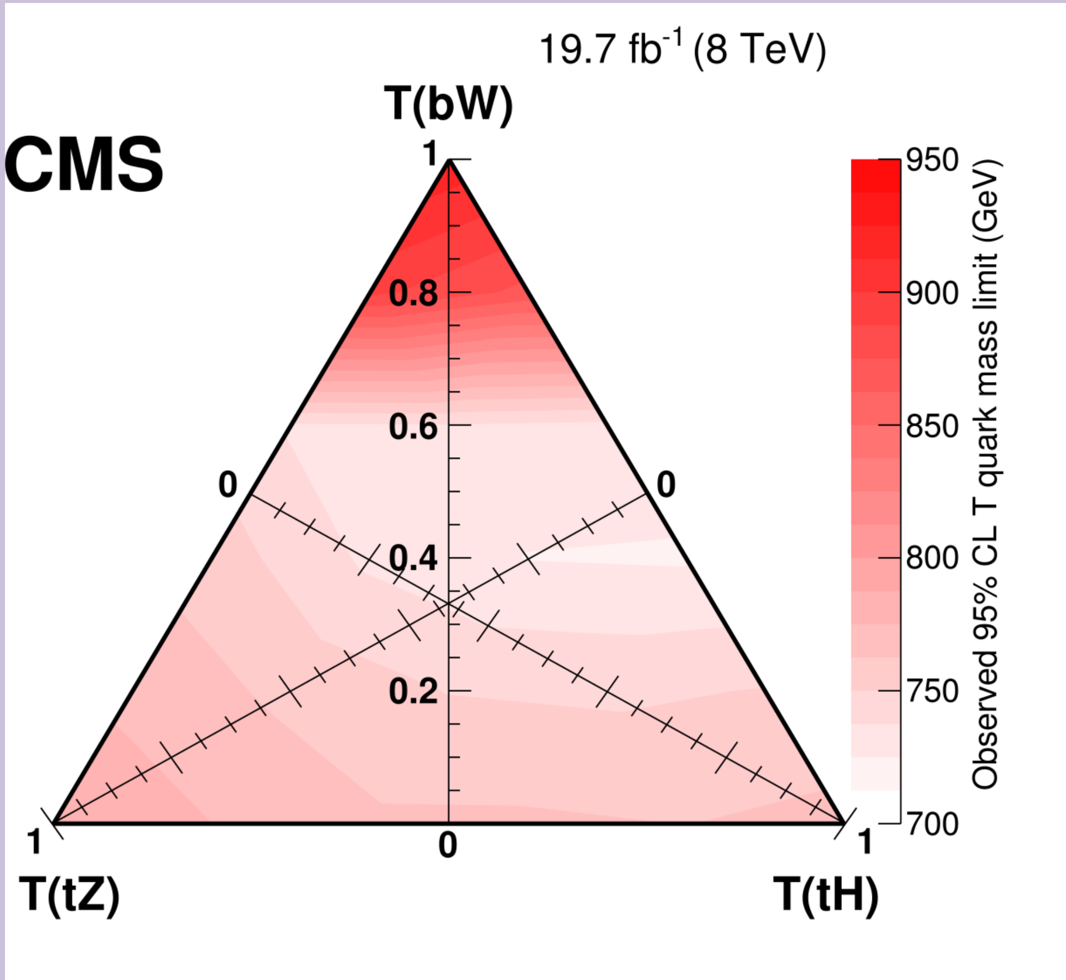
ATLAS-CONF-2015-044, CMS-PAS-HIG-15-002

- Test one-to-one prediction between mass and Higgs coupling in SM
- Important distinction between coupling fits and rate measurements



Suite of measurement possibilities

- Deviations in y_s or y_c (or any Yukawa) must be NP
  - Directly search for new vector-like fermion partners, additional Higgses



CMS [1509.04177]

Suite of measurement possibilities

- Deviations in y_s or y_c (or any Yukawa) must be NP
  - Measure in rare decays – $h \to MV$

See F. Petriello's talk

    - Kagan, Perez, Petriello, Soreq, Stoynev, Zupan [1406.1722]
    - Bodwin, Chung, Ee, Lee, Petriello [1407.6695]
    - Perez, Soreq, Stamou, Tobioka [1503.00290, 1505.06689]
    - König, Neubert [1505.03870]

Suite of measurement possibilities

- Deviations in y_s or y_c (or any Yukawa) must be NP
  - Measure in rare decays – h → MV

Bodwin, et. al. [1407.6695]

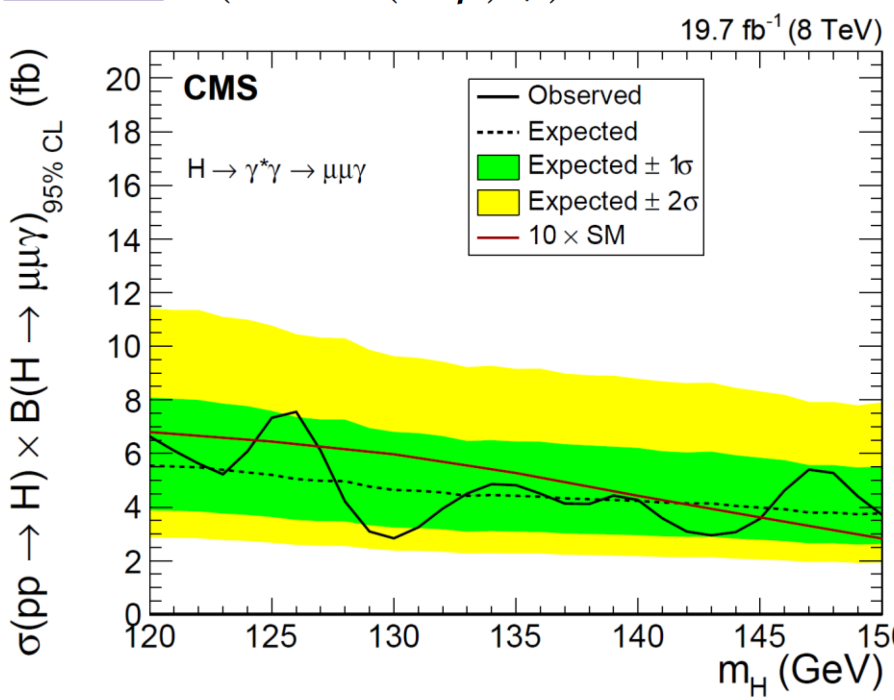
$$\mathcal{B}_{\rm SM}(H \to J/\psi + \gamma) = 2.79^{+0.16}_{-0.15} \times 10^{-6},$$

	95% CL Upper Limits				
	J/ψ	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\sum_n \Upsilon(nS)$
	$\mathcal{B}(Z \to \mathcal{Q}\gamma)$ [10^{-6}]				
Expected	$2.0^{+1.0}_{-0.6}$	$4.9^{+2.5}_{-1.4}$	$6.2^{+3.2}_{-1.8}$	$5.4^{+2.7}_{-1.5}$	$8.8^{+4.7}_{-2.5}$
Observed	2.6	3.4	6.5	5.4	7.9
	$\mathcal{B}(H \to \mathcal{Q}\gamma)$ [10^{-3}]				
Expected	$1.2^{+0.6}_{-0.3}$	$1.8^{+0.9}_{-0.5}$	$2.1^{+1.1}_{-0.6}$	$1.8^{+0.9}_{-0.5}$	$2.5^{+1.3}_{-0.7}$
Observed	1.5	1.3	1.9	1.3	2.0
	$\sigma(pp \to H) \times \mathcal{B}(H \to \mathcal{Q}\gamma)$ [fb]				
Expected	26^{+12}_{-7}	38^{+19}_{-11}	45^{+24}_{-13}	38^{+19}_{-11}	54^{+27}_{-15}
Observed	33	29	41	28	44

ATLAS [1501.03276]

CMS [1507.03031]

$$\mathcal{B}(\mathrm{H} \to (\mathrm{J}/\psi)\gamma) < 1.5 \times 10^{-3}$$

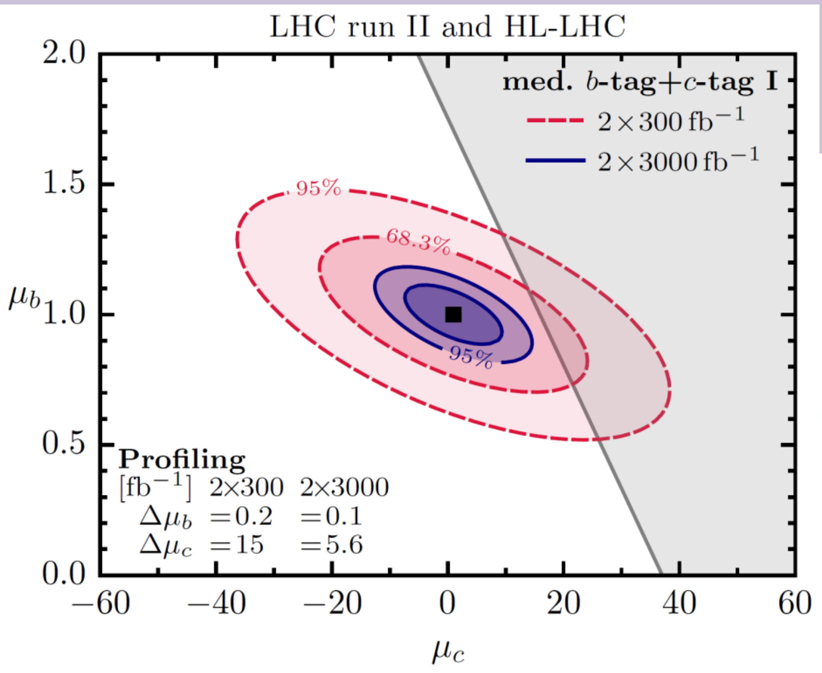


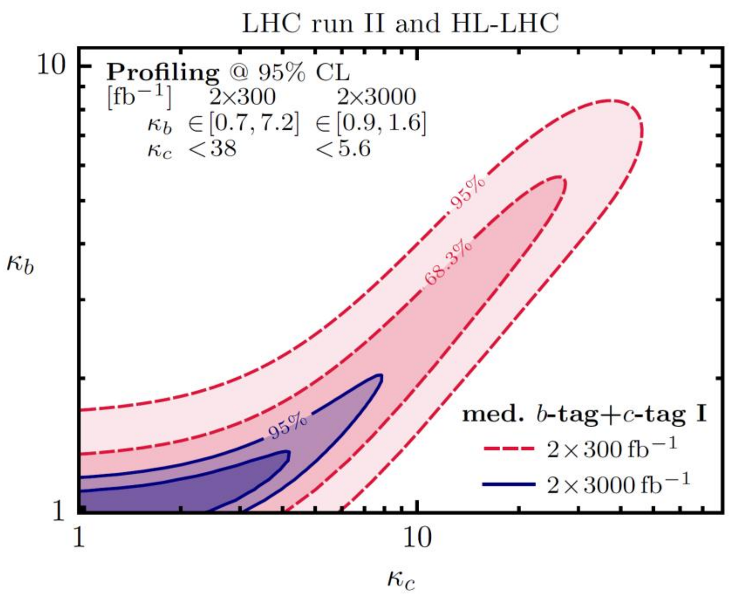
Suite of measurement possibilities

- Deviations in y_s or y_c (or any Yukawa) must be NP
  - Measure in direct decays

M_H = 125 GeV	Branching fraction	Relative error
H→bb	5.77E-1	+/- 3%
H→cc	2.91E-2	+/- 12%
H→ss	2.46E-4	+/- 5%
H→μμ	2.19E-4	+/- 6%

Higgs XSWG [1307.1347]





Perez, et. al. [1505.06689]

Suite of measurement possibilities

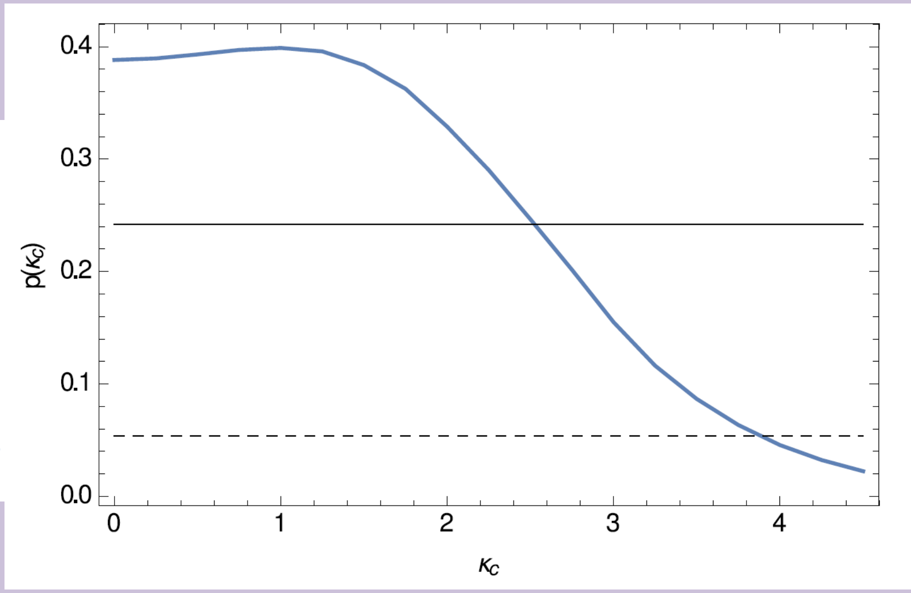
- Deviations in y_s or y_c (or any Yukawa) must be NP
  - Measure in h+c production (use $h \to \gamma\gamma$)
  - $p_T(j) > 20$ GeV
  - charm tag = 40%, gluon fake rate = 1%, b fake rate= 30%

Brivio, Goertz, Isidori [1507.02916]

κ_c	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2
S	874	877	885	899	917	941	973	1008	1052

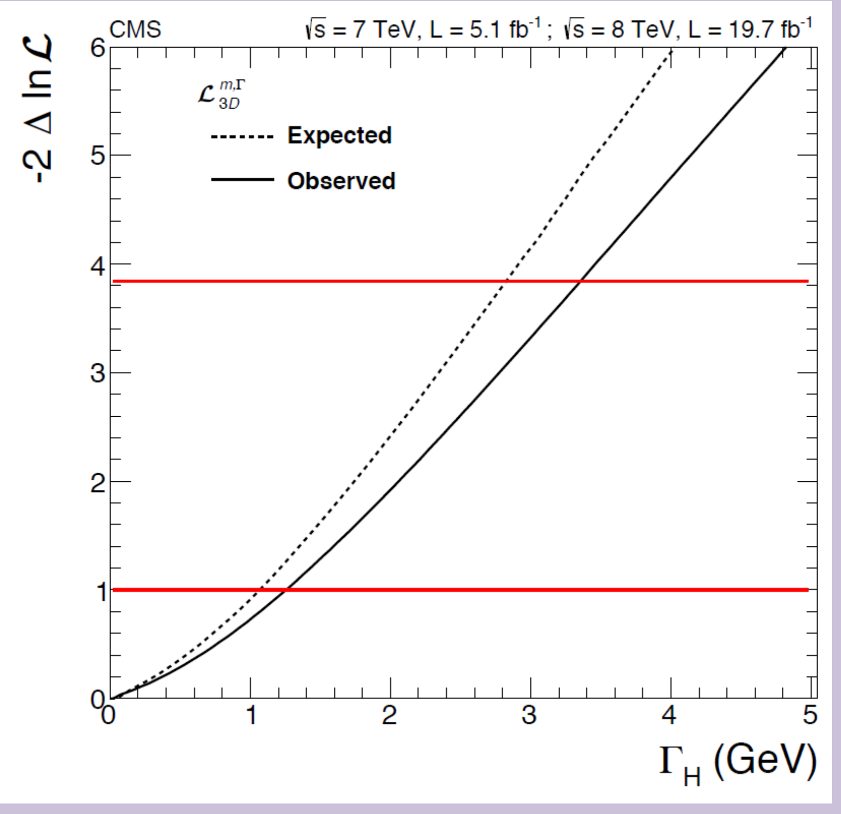
κ_c	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5
S	1097	1148	1206	1276	1350	1424	1504	1590	1683	1786

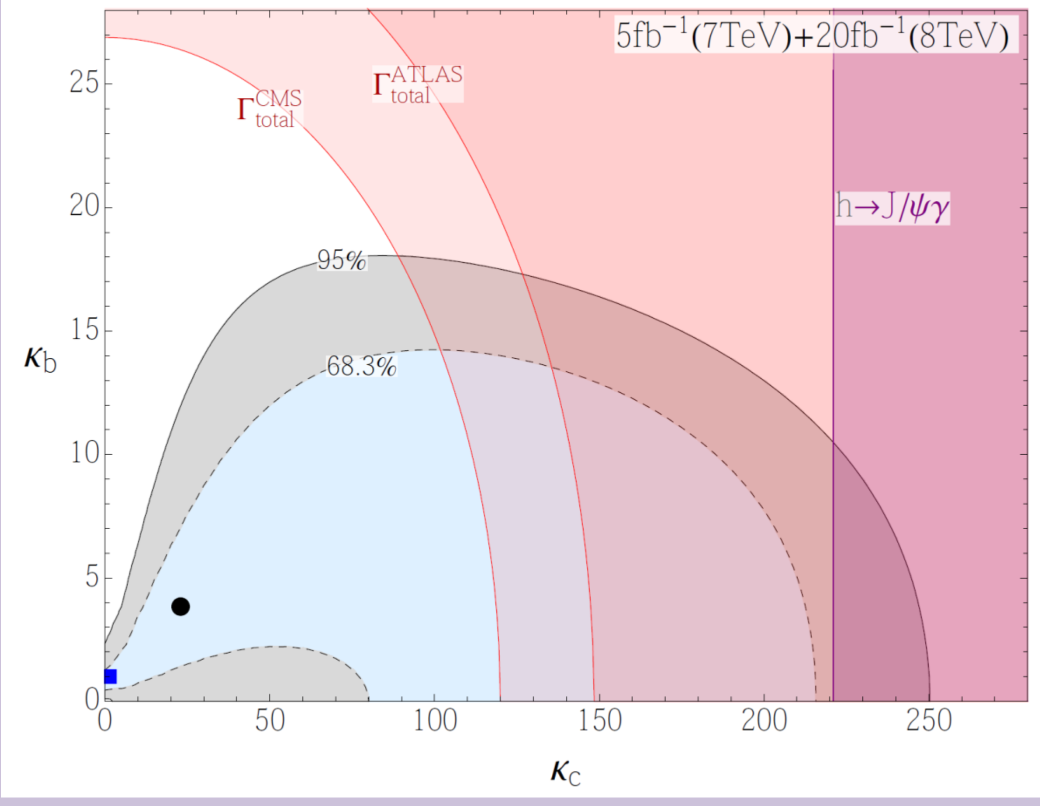
TABLE I. Number of Signal events $S(\kappa_c)$ in dependence on the charm-quark Yukawa coupling. See text for details.



Suite of measurement possibilities

- Deviations in y_s or y_c (or any Yukawa) must be NP
  - Higgs width measurements (direct)





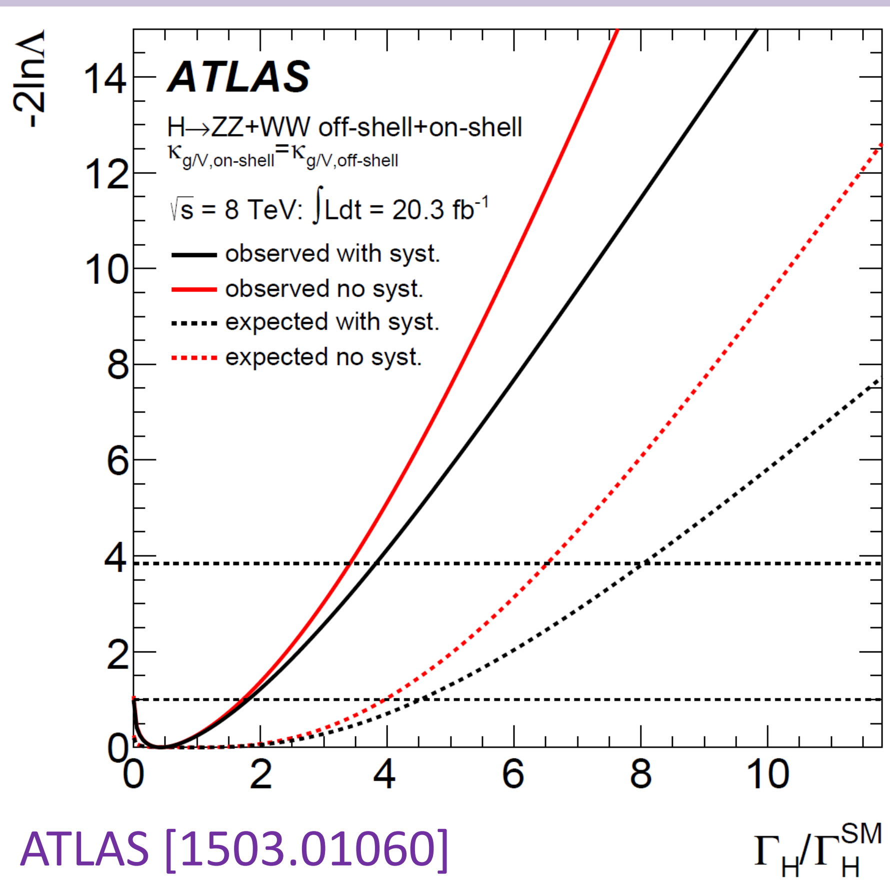
CMS [1312.5353]

Perez, et. al. [1503.00290]

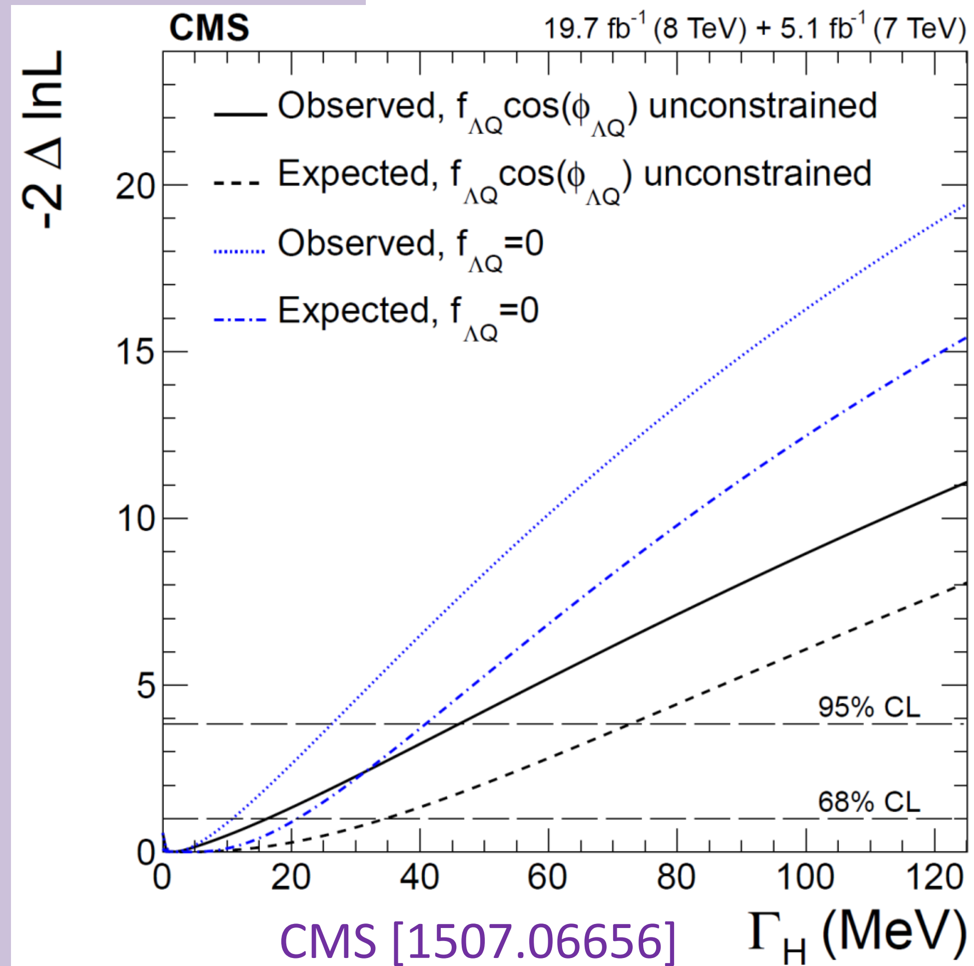
Suite of measurement possibilities

See talk by Dorival Goncalves

- Deviations in y_s or y_c (or any Yukawa) must be NP
  - Higgs width measurements (indirect) $\Gamma_H > 3.5 \times 10^{-9}$ MeV
    - Lower and upper bound



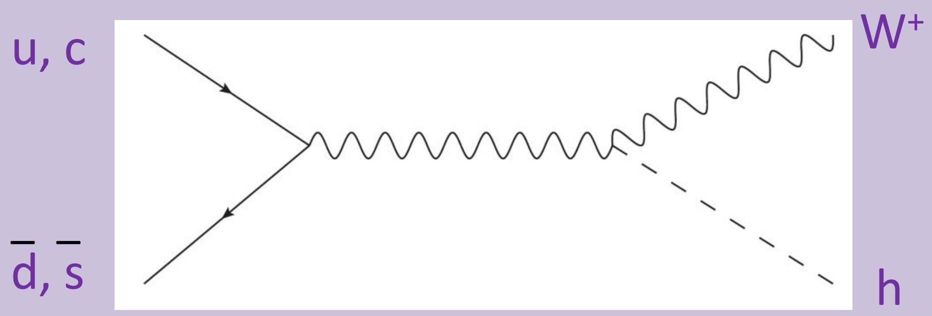
ATLAS [1503.01060]



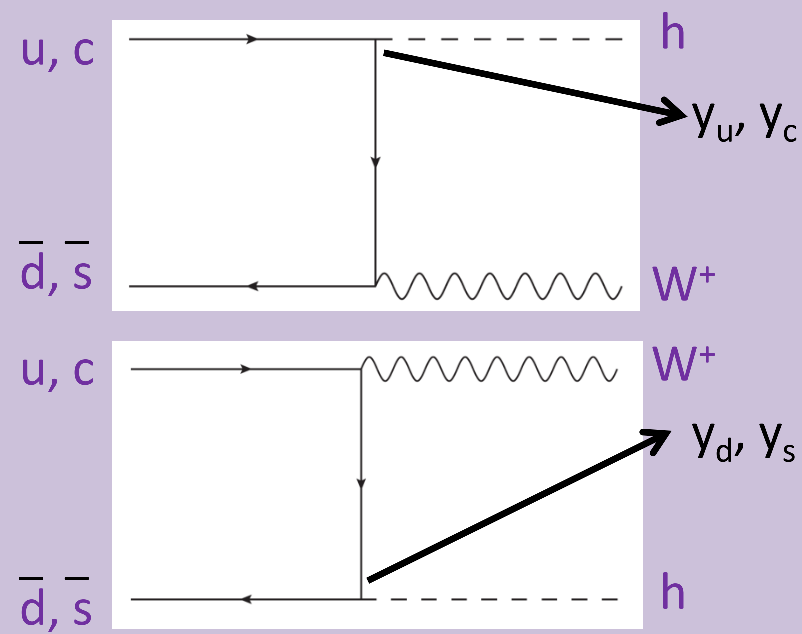
CMS [1507.06656]

Suite of measurement possibilities

- Deviations in y_s or y_c (or any Yukawa) must be NP
  - VH production (!?)
    - Provides an interesting handle on quark Yukawa couplings
  - In particular, consider W^+h and W^-h separately



Insensitive to Yukawas



See also Perez, et. al. [1503.00290] (only inclusive discussion)

Suite of measurement possibilities

- Deviations in y_s or y_c (or any Yukawa) must be NP
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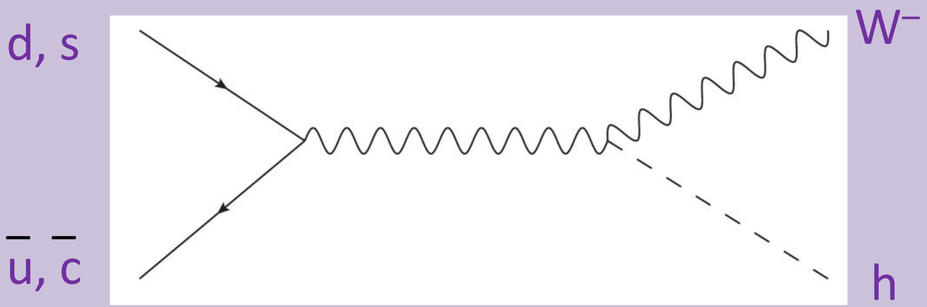
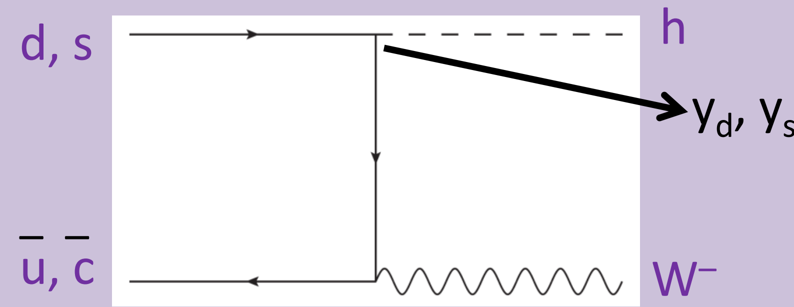
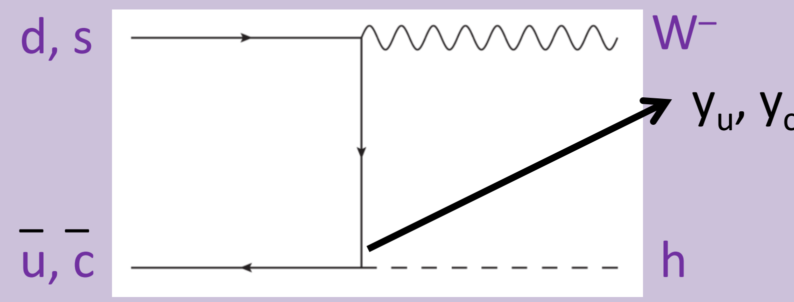


Insensitive to Yukawas





Suite of measurement possibilities

- Deviations in y_s or y_c (or any Yukawa) must be NP
  - Effective operator estimate (integrate out VLQs)

$$\mathcal{L} \supset yH\overline{Q}_L u_R + y' \frac{H^\dagger H}{\Lambda^2} H\overline{Q}_L u_R + \text{ h.c.}$$

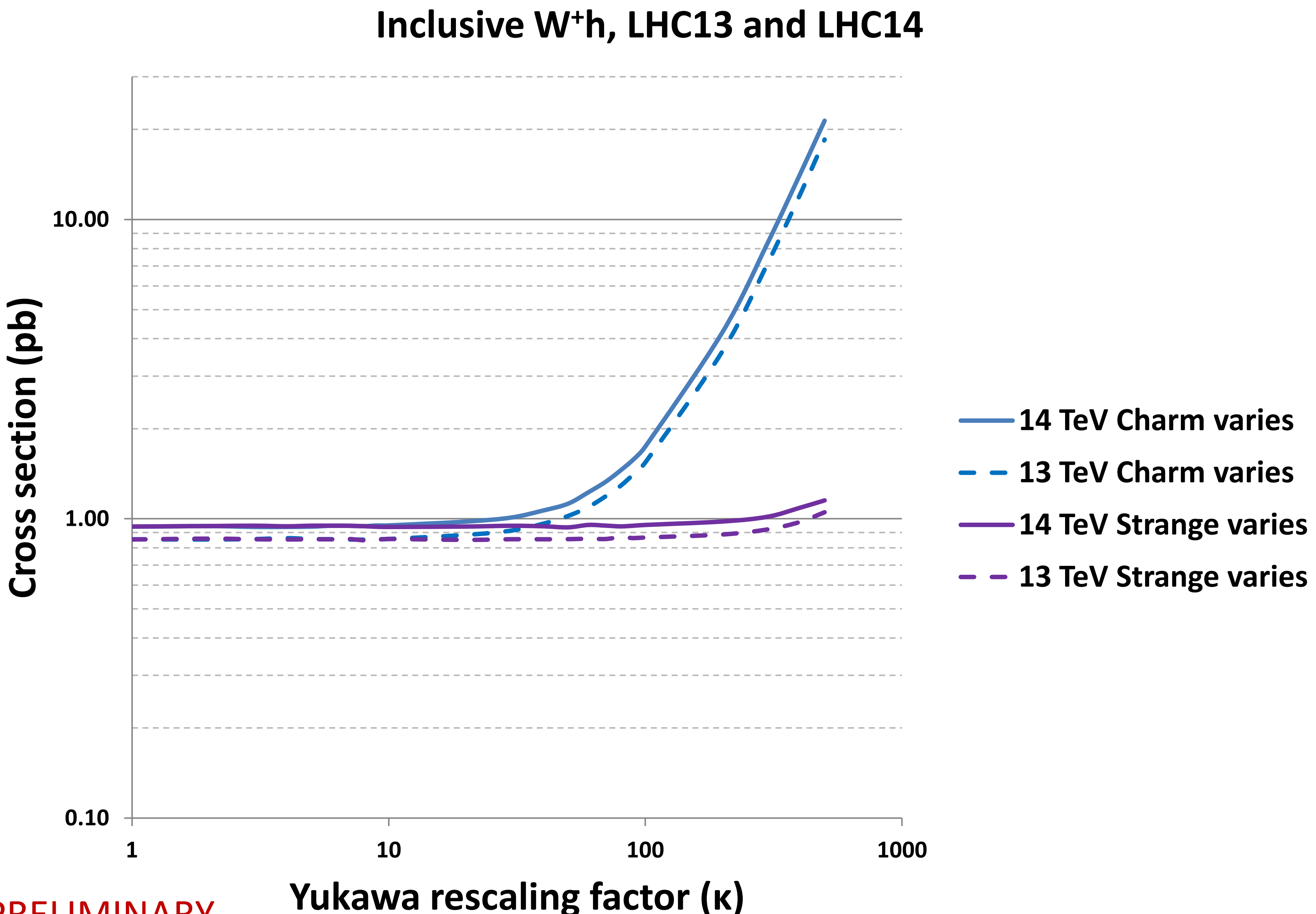
$$m_q = v\left(y + y'\frac{v^2}{\Lambda^2}\right)$$

$$y_q = \left(y + 3y'\frac{v^2}{\Lambda^2}\right)$$

$$\kappa_q \equiv \frac{y_q}{m_q/v} = \frac{\left(y + 3y'\frac{v^2}{\Lambda^2}\right)}{\left(y + y'\frac{v^2}{\Lambda^2}\right)} = 1 + \frac{2y'\frac{v^2}{\Lambda^2}}{y_{SM}}$$

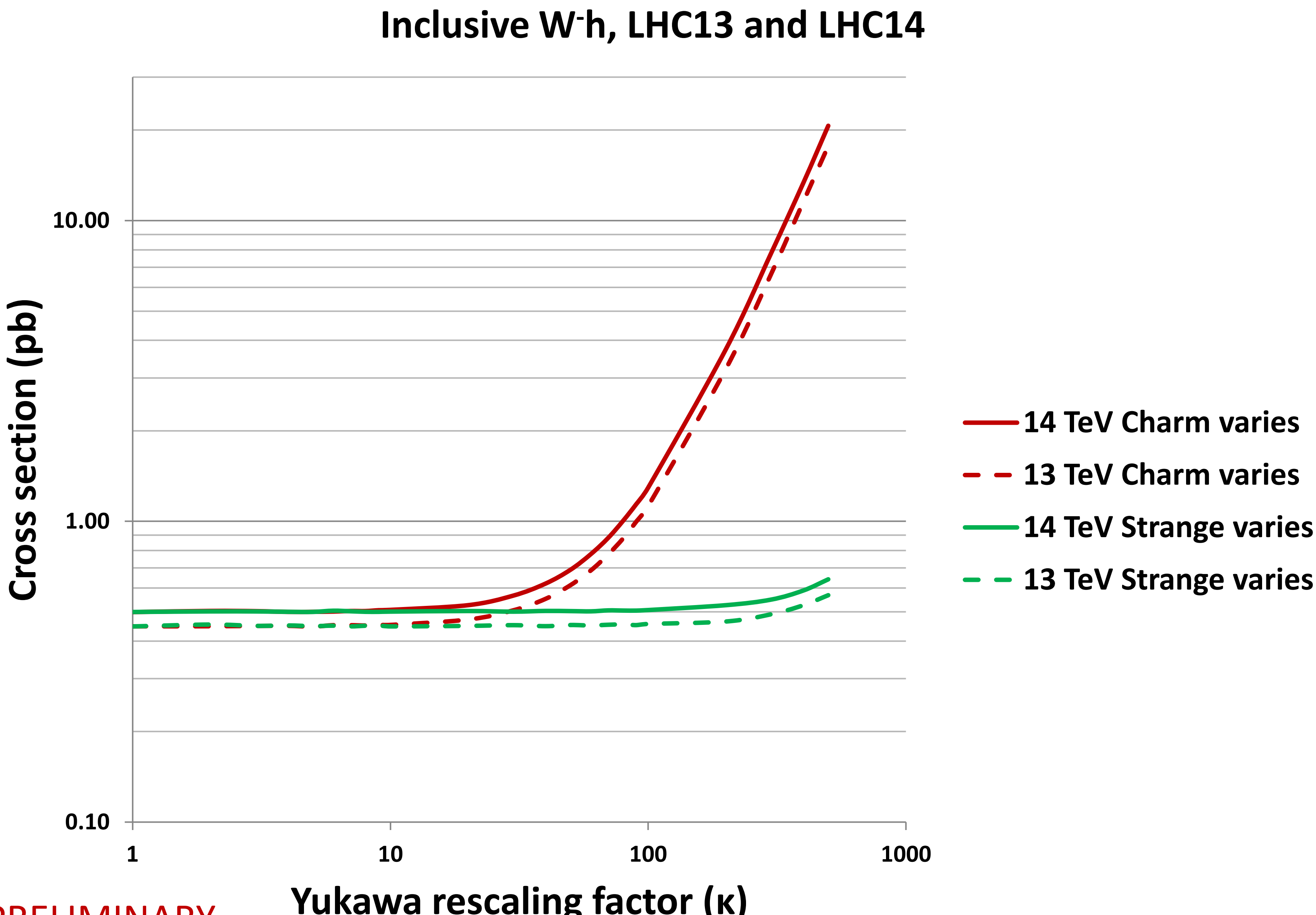
  - General argument to obtain large Yukawas for light fermions

W^+h cross section sensitivity



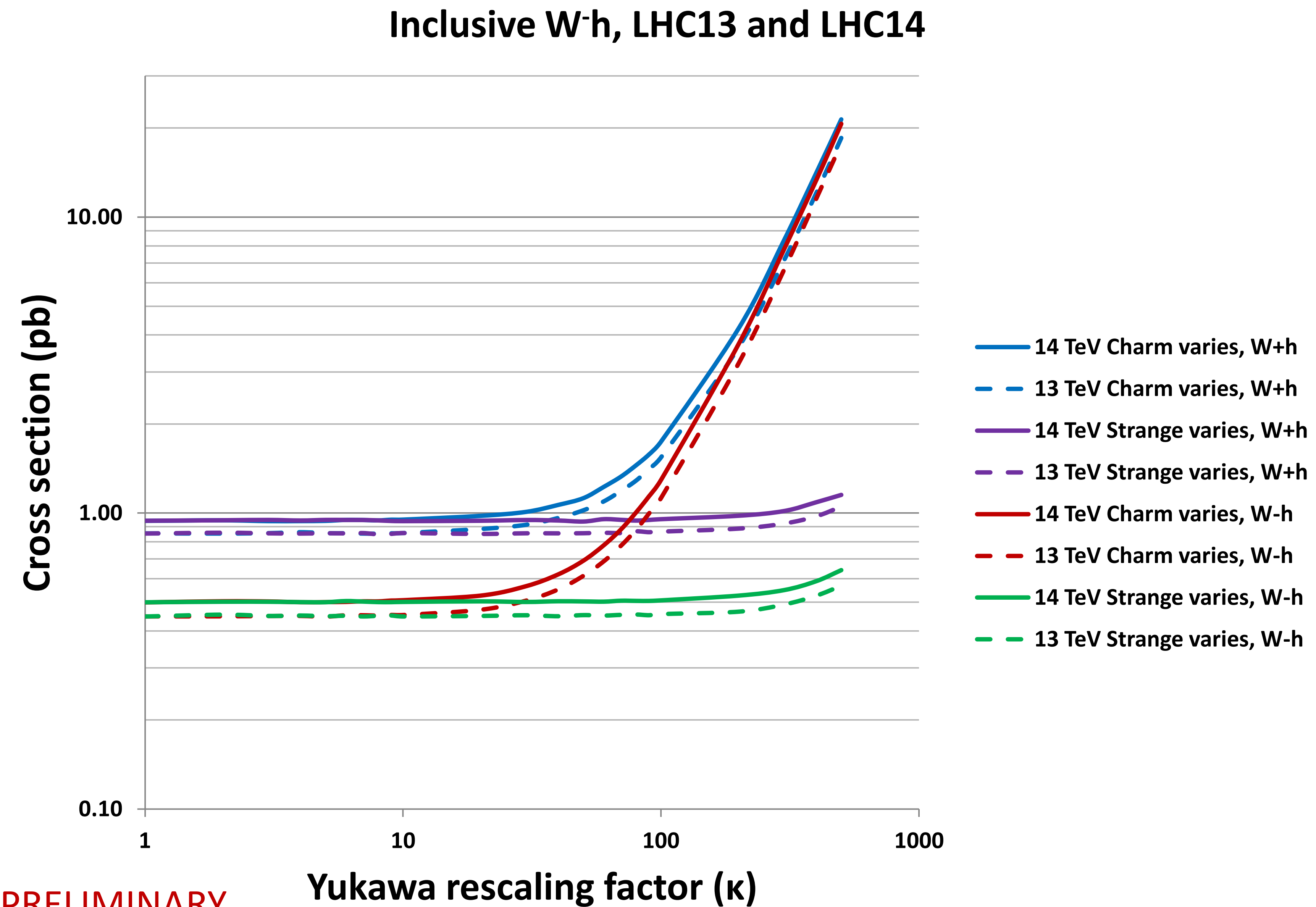
PRELIMINARY

W⁻h cross section sensitivity



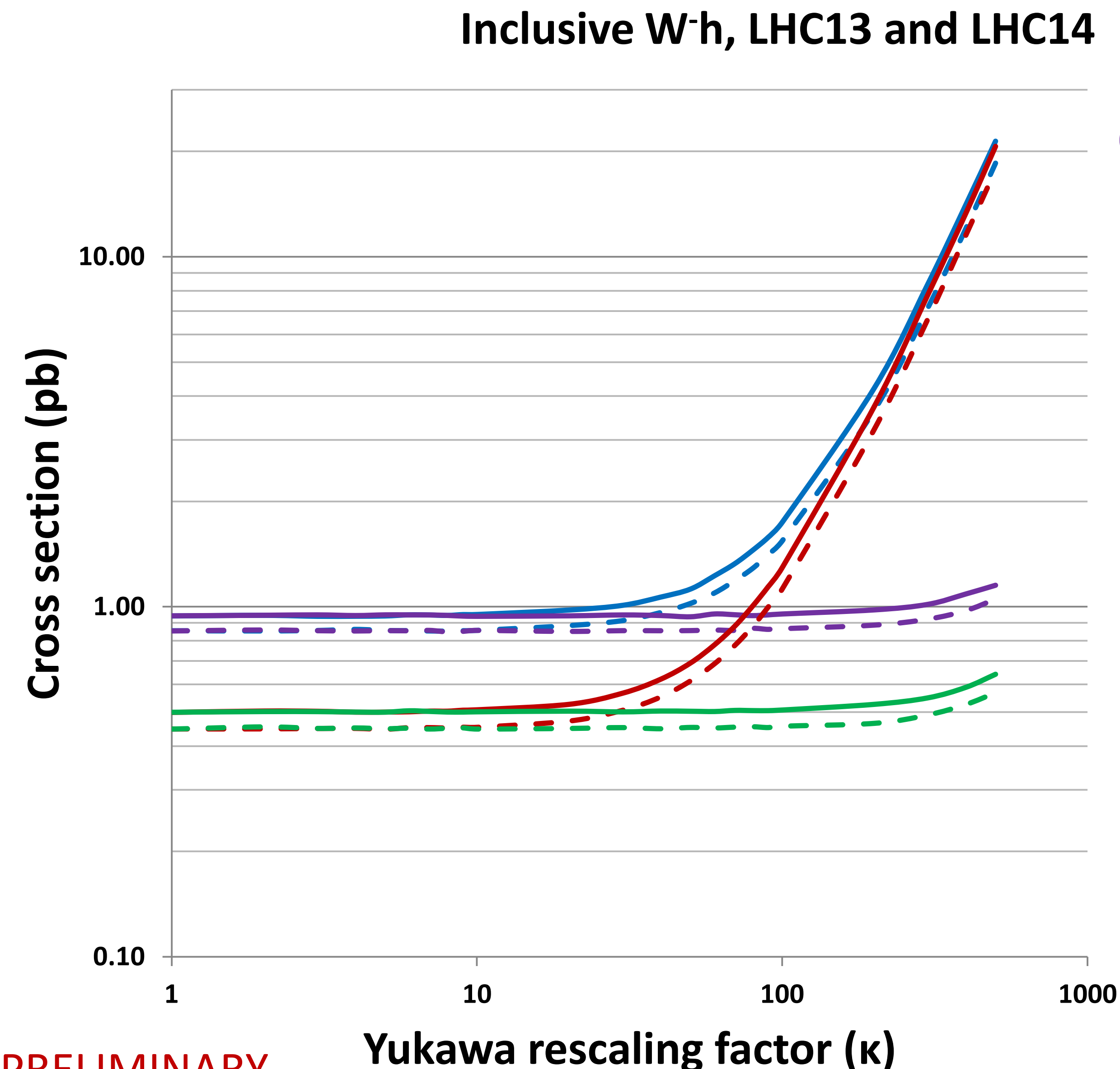
PRELIMINARY

Wh cross section sensitivity



PRELIMINARY

Wh cross section sensitivity



Charge asymmetry shows strong dependence on κ_c

PRELIMINARY

Measuring W^+h, W^-h rates

- Report μ separately for given W^+h, W^-h modes, given leptonic W decay
  - Motivates asymmetric cuts based on lepton charge

Higgs XSWG [1307.1347]

m_H (GeV)	8 TeV xsec (pb)	+QCD scale %	-QCD scale %	+(PDF+α_s) %	-(PDF+α_s) %	W^+H (pb)	W^-H (pb)
125	0.7046	1	-1	2.3	-2.3	0.445	0.2597

  - SM ratio of $\sigma(W^+h) / \sigma(W^-h)$ = 1.71, 1% uncertainty

Measuring W^+h, W^-h rates

PRELIMINARY

- Consider all possible final states that can give clean lepton asymmetry measurement

Using Standard Model BRs, include leptonic decays, # events for 3 ab^{-1} luminosity

		H→bb	H→γγ	$H \to l^+l^- l^+l^-$ ($l=e,\mu,\tau$)	$H \to l^+l^- l^+l^-$ ($l=e,\mu$)	$H \to l^+ l^- \nu_l \nu_l$ ($l=e$, μ or τ, ν=any)	$H \to l^+ l^- \nu_l \nu_l$ ($l=e$ or μ, ν=any)	H→ττ	$H \to l^+ l^- q q$ ($l=e,\mu$ or τ, q=udcsb)	$H \to l^+ \nu_l q q$ (*) ($l=e$ or μ, q=udcsb)
W^+h	300 fb^{-1}	31382	124	15	7	1288	579	3438	204	1730
W^+h	3 ab^{-1}	313816	1244	152	69	12880	5785	34383	2036	17301
W^-h	300 fb^{-1}	19150	76	9	4	786	353	2098	124	1056
W^-h	3 ab^{-1}	191498	759	93	42	7860	3530	20982	1242	10557

- Have 17k same-sign ++ Higgs events, 10.5k same-sign – events, same asymmetry behavior as W^+h vs. W^-h

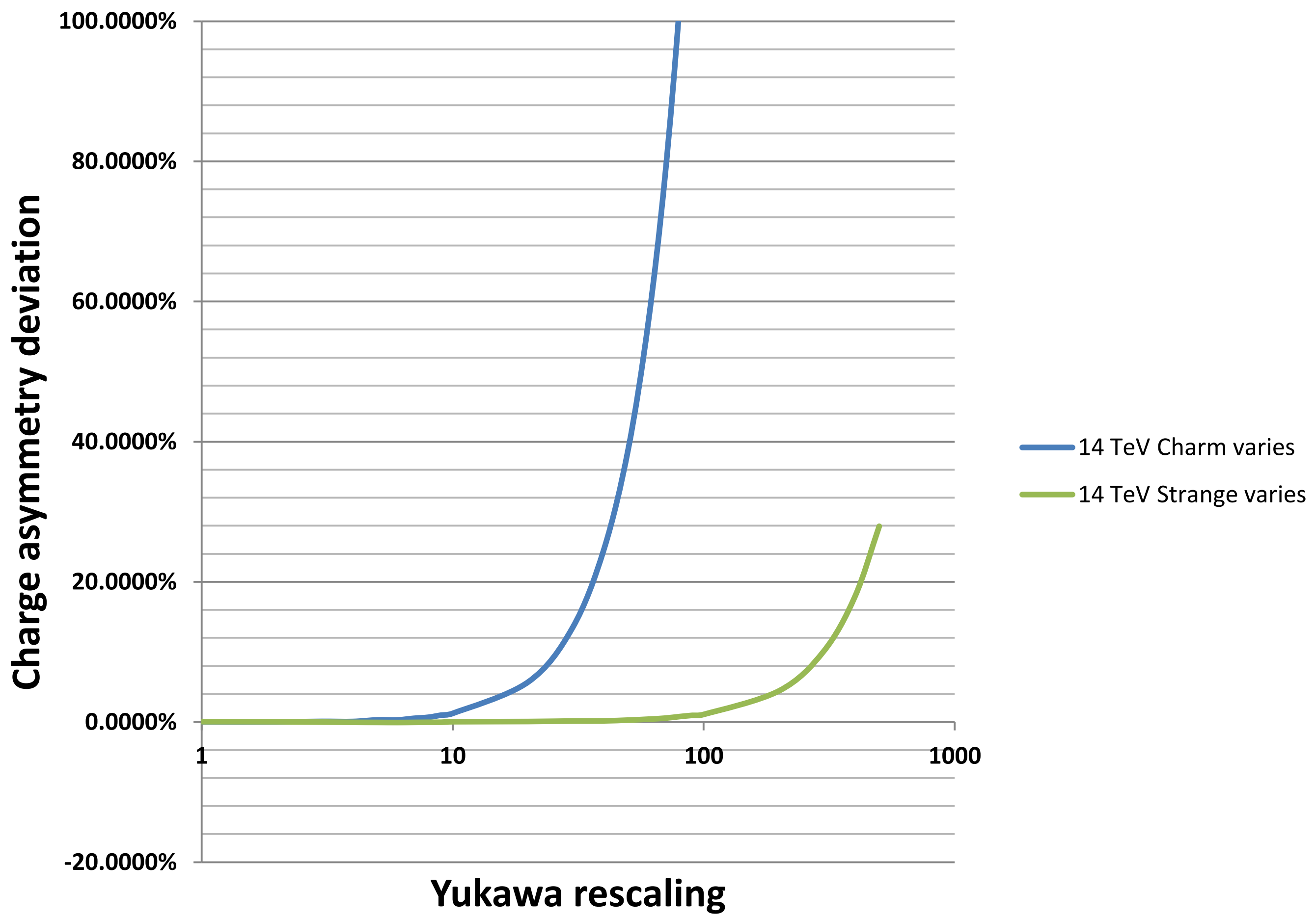
Measuring W^+h, W^-h rates

- PDF uncertainties will be key ingredient to control theory error on inclusive rate sensitivity and asymmetry deviation
    - See Stirling, Vryonidou [1203.6781] for prospects for PDF constraints from W+c (strange PDF), Z+c (charm PDF) measurements, also ATLAS [1402.6263]

Measuring W^+h, W^-h rates

PRELIMINARY

- Naïve sensitivity estimate gives κ_c bound within 10-20, κ_s within O(100)



Conclusions

- New idea for measuring charm and strange (and also possibly up and down) Yukawa couplings
- Reoptimize VH searches for
  – Use self-consistency test in VBF production to test κ_V deviation
- Different systematics and experimental challenges than charm tagging and rare decays
  – Precise theory estimation of sensitivity relies on strange and charm PDF – need Z+c production measurement