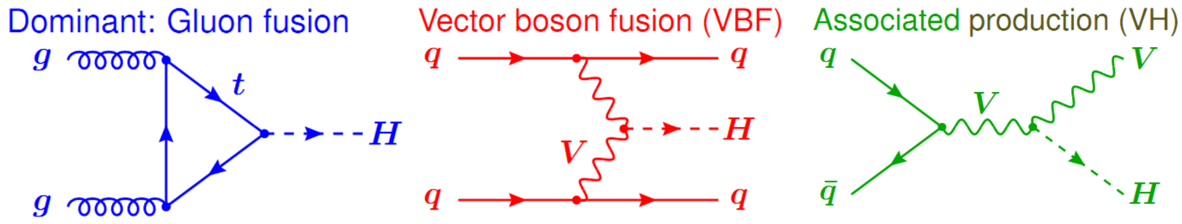
The properties of the X particle at the LHC

Lunch discussions, SMU

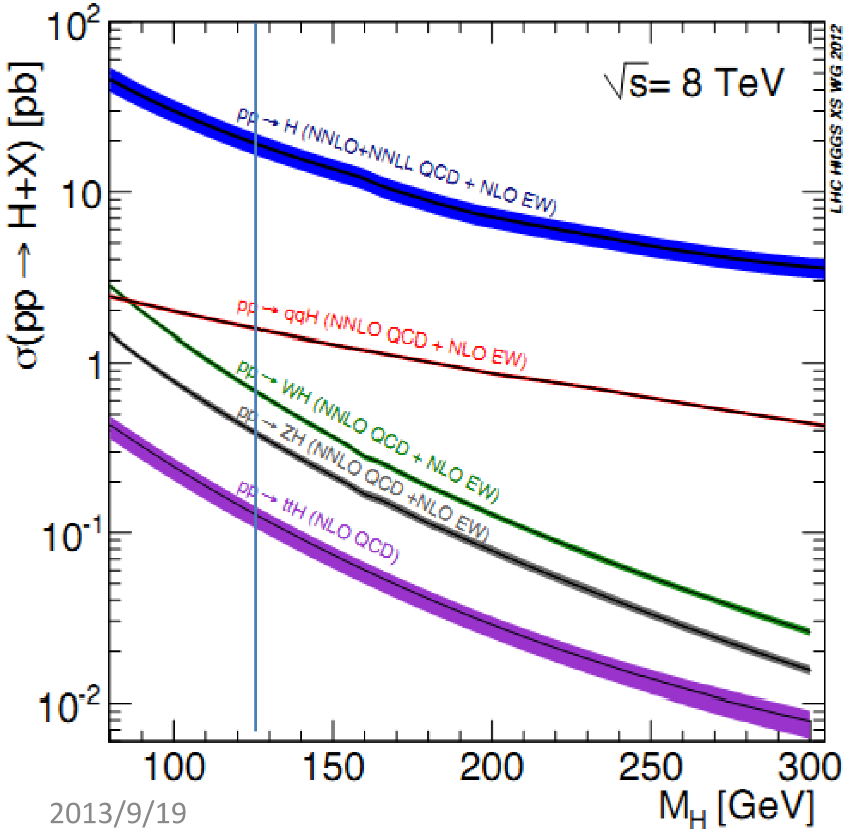
Jun Gao, 9/18/2013

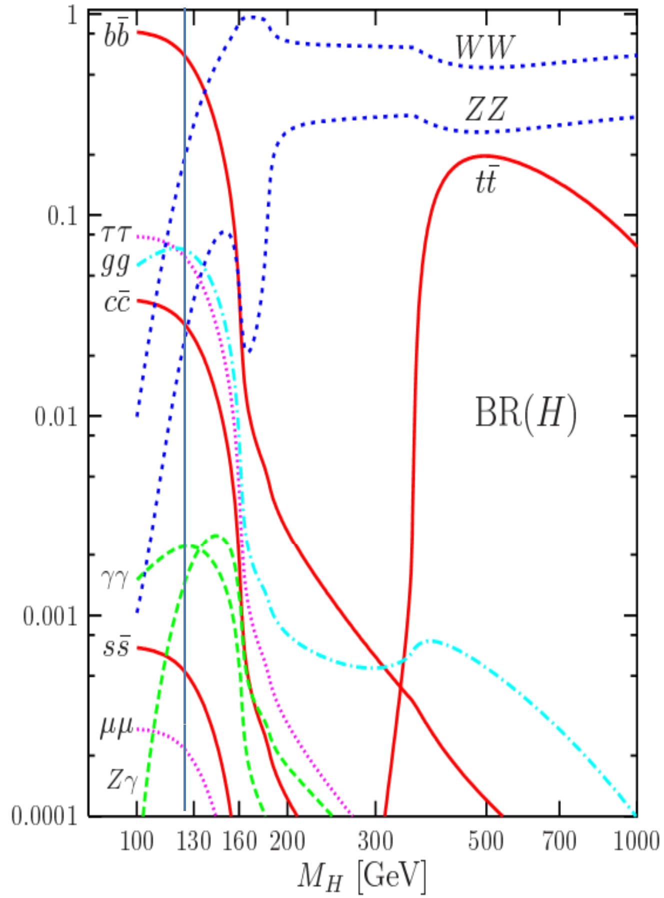
● Higgs boson in the SM: production and decay



Other important channels: H+b, H+tt, HH, H+jets

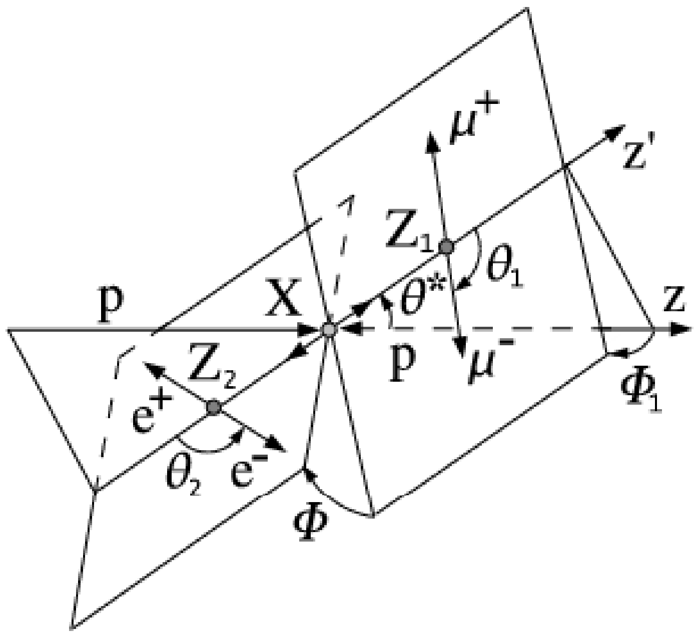
hep-ph/0503172





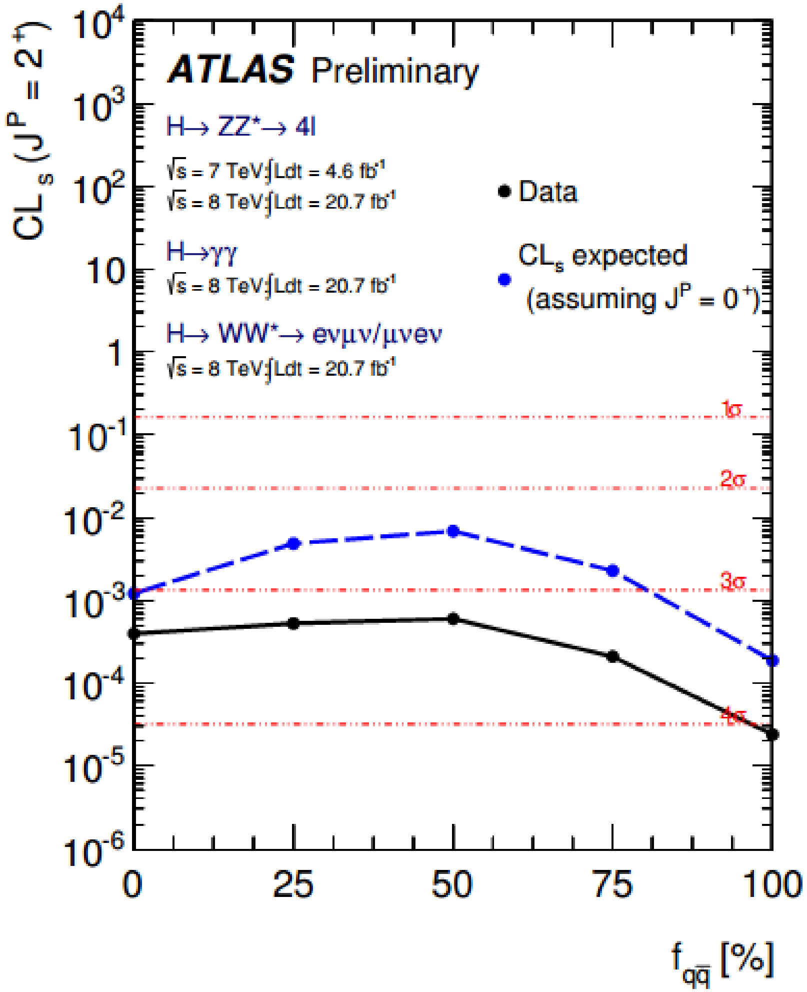
The X particle: Spin determination

Spin-0 vs. Spin-2: augular distributions, most common observables used for the discrimination



Note the model dependences, especially for the spin-2 case. Various couplings give different shapes and may mimic the spin-0 case.

arXiv: 1001.3396



ATLAS-CONF-2013-040

● The X particle: Couplings-Width-Invisible

Most general final states for 2-body decay (blind search):
1, AA, ZZ*, WW*, AZ, tautau; ★ ★ ★ ★ ★
2, bb, cc; ★ ★ ★
3, gg (qq); ★
3, vv, or other invisible channels;

SM Higgs, or scalar particle with modified couplings (self couplings, HAZ, not included here):

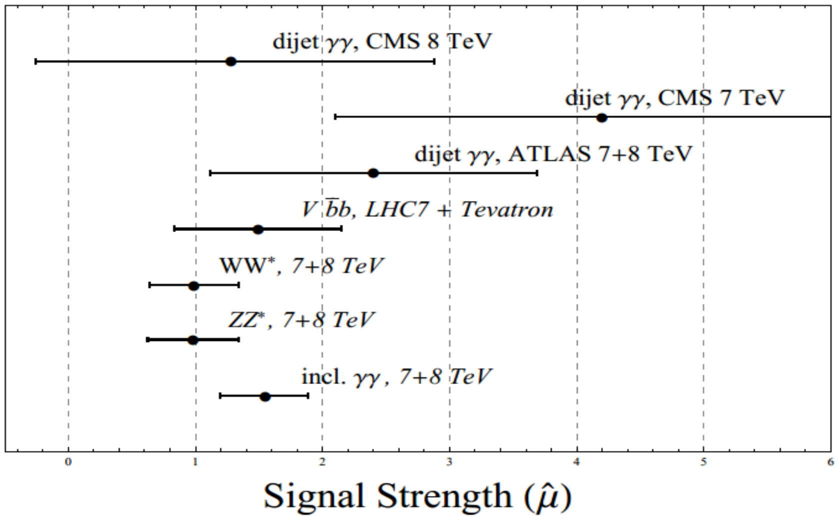
$$\mathcal{L}_{eff} = c_V \frac{2m_W^2}{v} h\, W_\mu^+ W_\mu^- + c_V \frac{m_Z^2}{v} h\, Z_\mu Z_\mu - c_b \frac{m_b}{v} h\, \bar{b}b - c_\tau \frac{m_\tau}{v} h\, \bar{\tau}\tau - c_c \frac{m_c}{v} h\, \bar{c}c$$
$$+ c_g \frac{\alpha_s}{12\pi v} h\, G_{\mu\nu}^a G_{\mu\nu}^a + c_\gamma \frac{\alpha}{\pi v} h\, A_{\mu\nu} A_{\mu\nu} - c_{inv} h\, \bar{\chi}\chi\ .$$

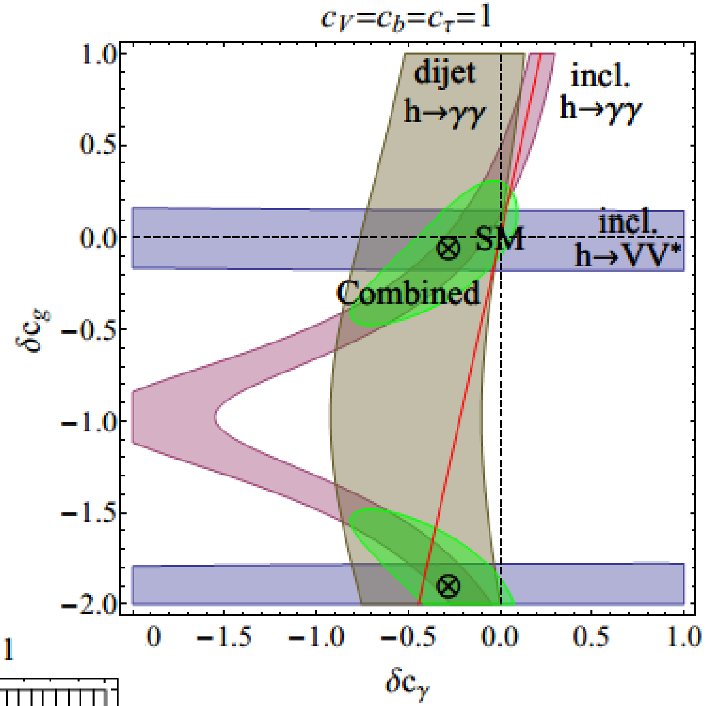
arXiv: 1207.1718

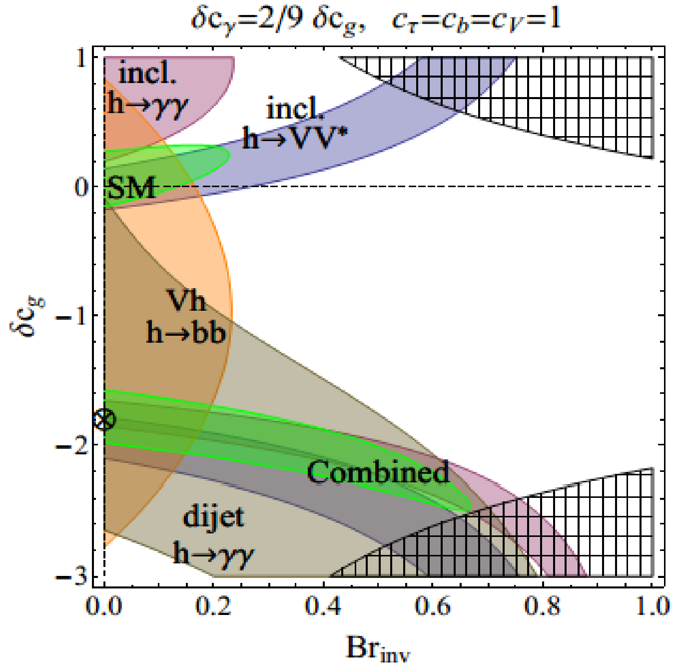
In the narrow width approximation, observed rate always proportional to (c1*c2)^2/Gamma(H), thus how to measure the absolute strength of the Higgs couplings? E.g., from inclusive rate we can get ca/cv …, take the ratio of VBF or VH with inclusive, we can get cg/cv . All are relative strength. Must make assumptions to get the absolute strength.

● The X particle: Example of a global fit

Experimental input:







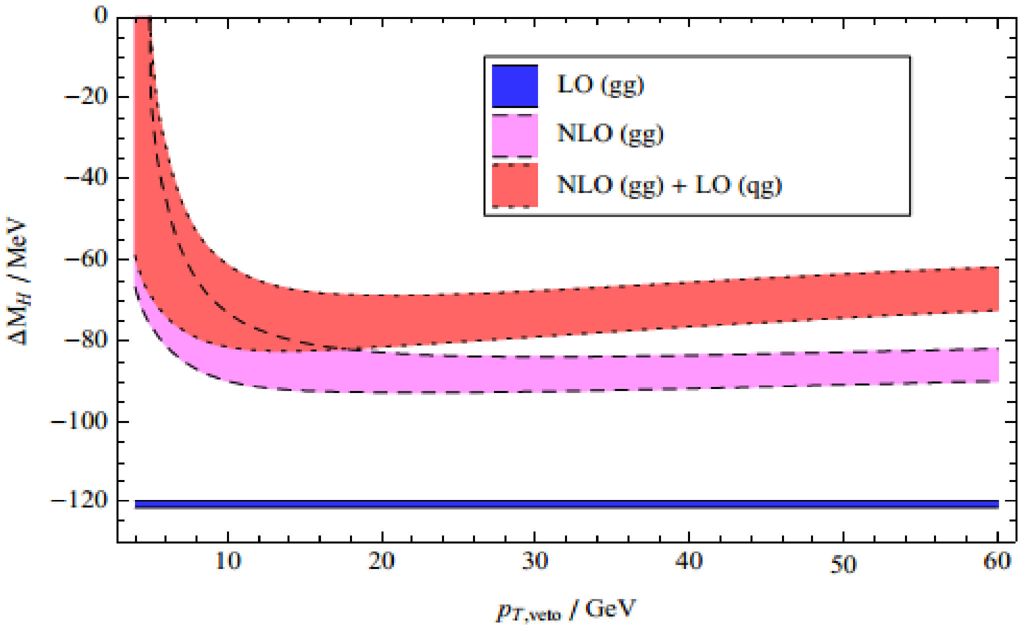
arXiv: 1207.1718

● The X particle: Can we get the total width?

Direct measurement from the resonant shape: impossible, width~4 MeV for SM, while the experiment resolution is a few GeV

Indirect measurements using the interference with SM backgrounds and off-shell effects, two examples:

1, Using apparent mass shift, |mAA-mZZ| that is sensitive to cg*cA, which could be related to the total width under certain assumptions



arXiv: 1305.3854

Upper bound can be obtained ~ 10*Gamma(H,SM) with high luminosities for both two methods

arXiv: 1307.4935

2, Using rate of ZZ production above the Higgs mass that is proportional to cg*cv

● The X particle: qq or gg in the direct production?

Motivation: In the SM, the direct production is dominated by gg initial state. While in 2HDM, the cc or bb contribution can be largely enhanced, or even the light quark contributions can be significant for the spin-2 case. Can we distinguish them?

Difficult to separate ggH and qqH, especially the light quarks, through the decay (all jets or heavy jets). But there are two essential distinctions we can use in the production, PDFs and initial state radiations (QCD or QED). Both of them are model-independent, not rely on the detailed structures of the couplings.

arXiv: 1308.5453

Benchmark models (three models):
A, spin-0, gg dominant (SM case)
B, spin-0, bb, cc dominant
C, spin-2, light quark dominant

$$\mathcal{L}_{spin-0} = \frac{g_1^{(0)}}{v} H G^{\mu\nu} G_{\mu\nu} + \frac{g_2^{(0)}}{v} (m_c H \bar{\Psi}_c \Psi_c + m_b H \bar{\Psi}_b \Psi_b)$$

$$\mathcal{L}_{spin-2} = g_1^{(2)} Y_{\mu\nu} T_G^{\mu\nu} + g_2^{(2)} Y_{\mu\nu} T_q^{\mu\nu}$$

Inclusive observables:
1, R(L7/T), R(L14/L7)…
2, R(|y|<1/|y|<infinity)
3, R(HA/H)
All ratios not reply on the decay BR.

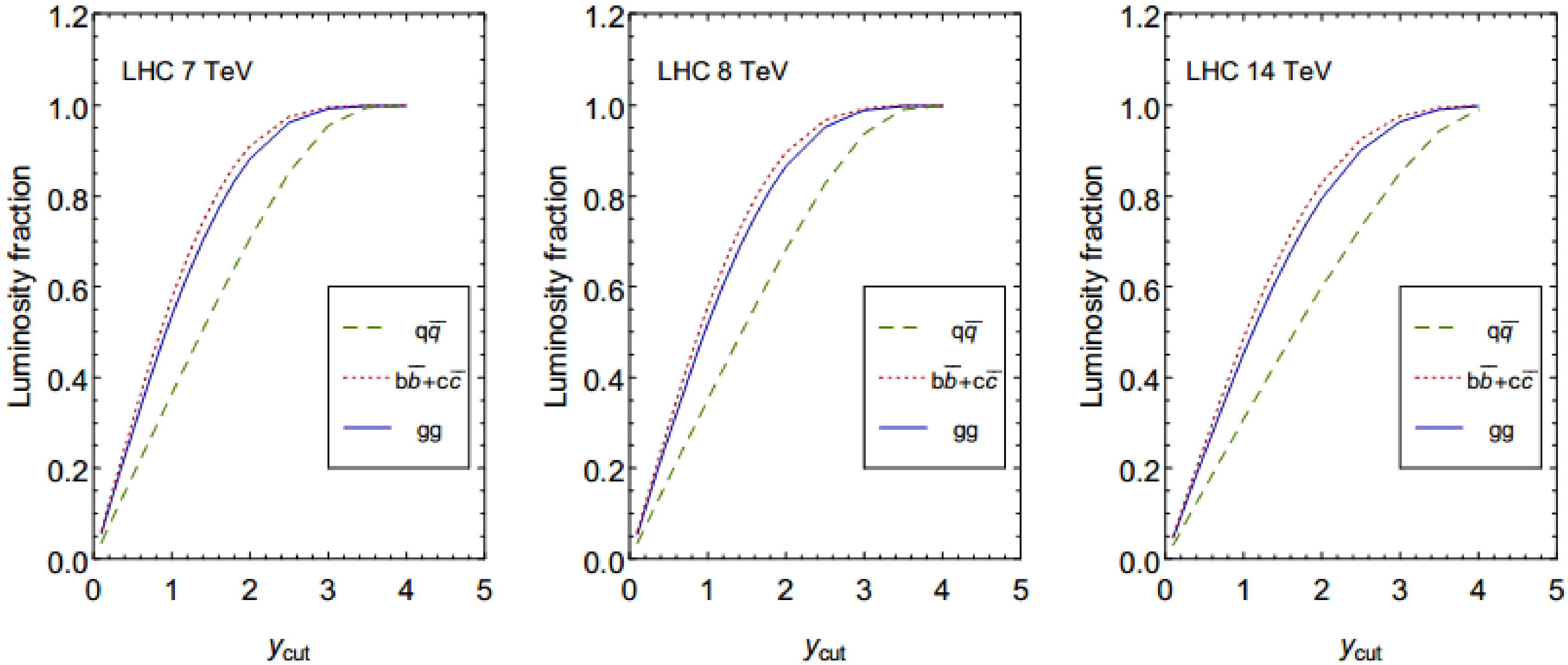
Ratio of the direct production cross sections

model A	CT10			MSTW08			NNPDF2.3			Combined
	LO	NLO	NNLO	LO	NLO	NNLO	LO	NLO	NNLO	NNLO
$R^1_{L7/T}$	$17.9^{+0.8}_{-1.0}$	$17.5^{+0.8}_{-0.9}$	$17.0^{+0.7}_{-0.9}$	$18.1^{+0.5}_{-0.5}$	$17.7^{+0.5}_{-0.5}$	$17.2^{+0.5}_{-0.5}$	$18.6^{+0.6}_{-0.6}$	$18.1^{+0.6}_{-0.5}$	$17.5^{+0.5}_{-0.5}$	$17.1^{+1.1}_{-1.1}$
$R^1_{L8/T}$	$22.9^{+1.1}_{-1.3}$	$22.4^{+1.0}_{-1.2}$	$21.7^{+1.0}_{-1.2}$	$23.2^{+0.7}_{-0.7}$	$22.6^{+0.7}_{-0.7}$	$21.9^{+0.7}_{-0.7}$	$23.9^{+0.8}_{-0.8}$	$23.2^{+0.7}_{-0.7}$	$22.4^{+0.7}_{-0.7}$	$21.8^{+1.5}_{-1.5}$
$R^1_{L14/T}$	$59.9^{+3.4}_{-4.1}$	$58.5^{+3.1}_{-3.8}$	$56.3^{+3.0}_{-3.6}$	$60.7^{+2.3}_{-2.2}$	$59.3^{+2.2}_{-2.1}$	$57.0^{+2.1}_{-2.0}$	$62.2^{+2.4}_{-2.3}$	$60.6^{+2.2}_{-2.1}$	$58.1^{+2.1}_{-2.0}$	$56.6^{+4.3}_{-4.3}$
$R^1_{L14/L7}$	$3.34^{+0.04}_{-0.05}$	$3.35^{+0.04}_{-0.05}$	$3.32^{+0.04}_{-0.05}$	$3.35^{+0.03}_{-0.03}$	$3.35^{+0.03}_{-0.03}$	$3.32^{+0.03}_{-0.03}$	$3.34^{+0.03}_{-0.03}$	$3.34^{+0.03}_{-0.02}$	$3.31^{+0.02}_{-0.02}$	$3.31^{+0.05}_{-0.05}$
$R^1_{L14/L8}$	$2.61^{+0.02}_{-0.03}$	$2.62^{+0.02}_{-0.03}$	$2.60^{+0.02}_{-0.03}$	$2.62^{+0.02}_{-0.02}$	$2.62^{+0.02}_{-0.02}$	$2.60^{+0.02}_{-0.02}$	$2.61^{+0.02}_{-0.02}$	$2.61^{+0.02}_{-0.01}$	$2.59^{+0.01}_{-0.01}$	$2.59^{+0.03}_{-0.03}$

model B	CT10			MSTW08			NNPDF2.3			Combined
	LO	NLO	NNLO	LO	NLO	NNLO	LO	NLO	NNLO	NNLO
$R^1_{L7/T}$	$23.0^{+1.5}_{-1.8}$	$22.7^{+1.6}_{-1.9}$	$23.4^{+1.7}_{-2.0}$	$23.5^{+1.0}_{-1.0}$	$23.2^{+1.1}_{-1.1}$	$24.0^{+1.2}_{-1.2}$	$24.6^{+1.2}_{-1.2}$	$24.4^{+1.3}_{-1.2}$	$25.3^{+1.5}_{-1.4}$	$24.2^{+3.2}_{-3.2}$
$R^1_{L8/T}$	$29.8^{+2.1}_{-2.5}$	$29.4^{+2.2}_{-2.6}$	$30.4^{+2.4}_{-2.8}$	$30.5^{+1.4}_{-1.4}$	$30.0^{+1.5}_{-1.5}$	$31.2^{+1.7}_{-1.7}$	$32.0^{+1.7}_{-1.6}$	$31.6^{+1.8}_{-1.7}$	$33.0^{+2.0}_{-1.9}$	$31.4^{+4.3}_{-4.3}$
$R^1_{L14/T}$	$81.2^{+6.6}_{-7.8}$	$79.4^{+6.8}_{-7.9}$	$82.8^{+7.5}_{-8.6}$	$83.1^{+4.7}_{-4.6}$	$81.6^{+5.0}_{-4.8}$	$85.3^{+5.6}_{-5.4}$	$87.4^{+5.2}_{-4.9}$	$85.8^{+5.5}_{-5.1}$	$90.0^{+6.2}_{-5.7}$	$85.6^{+13.1}_{-13.1}$
$R^1_{L14/L7}$	$3.53^{+0.06}_{-0.07}$	$3.50^{+0.06}_{-0.07}$	$3.54^{+0.06}_{-0.08}$	$3.54^{+0.04}_{-0.04}$	$3.52^{+0.04}_{-0.04}$	$3.55^{+0.05}_{-0.04}$	$3.54^{+0.04}_{-0.04}$	$3.52^{+0.04}_{-0.04}$	$3.55^{+0.04}_{-0.04}$	$3.53^{+0.09}_{-0.09}$
$R^1_{L14/L8}$	$2.72^{+0.03}_{-0.04}$	$2.70^{+0.04}_{-0.04}$	$2.72^{+0.04}_{-0.04}$	$2.73^{+0.02}_{-0.02}$	$2.71^{+0.03}_{-0.02}$	$2.73^{+0.03}_{-0.03}$	$2.73^{+0.02}_{-0.02}$	$2.71^{+0.02}_{-0.02}$	$2.73^{+0.02}_{-0.02}$	$2.72^{+0.05}_{-0.05}$

model C	CT10	MSTW08	NNPDF2.3	Combined
	LO	LO	LO	LO
$R^1_{L7/T}$	$3.96^{+0.07}_{-0.06}$	$4.00^{+0.04}_{-0.06}$	$3.95^{+0.06}_{-0.05}$	$3.98^{+0.10}_{-0.10}$
$R^1_{L8/T}$	$4.68^{+0.08}_{-0.08}$	$4.72^{+0.05}_{-0.07}$	$4.67^{+0.07}_{-0.06}$	$4.70^{+0.12}_{-0.12}$
$R^1_{L14/T}$	$9.17^{+0.20}_{-0.20}$	$9.19^{+0.13}_{-0.16}$	$9.10^{+0.14}_{-0.12}$	$9.18^{+0.25}_{-0.25}$
$R^1_{L14/L7}$	$2.32^{+0.02}_{-0.02}$	$2.30^{+0.01}_{-0.01}$	$2.30^{+0.01}_{-0.01}$	$2.31^{+0.02}_{-0.02}$
$R^1_{L14/L8}$	$1.96^{+0.01}_{-0.01}$	$1.94^{+0.01}_{-0.01}$	$1.95^{+0.01}_{-0.01}$	$1.96^{+0.02}_{-0.02}$

Centrality Ratio



XA production (not XV)