SQEEZED NEW PHYSICS IN TOP-QUARK PAIR PRODUCTION

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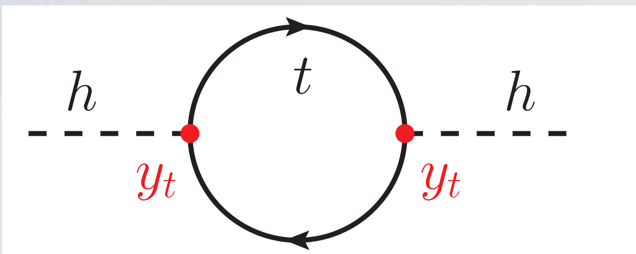
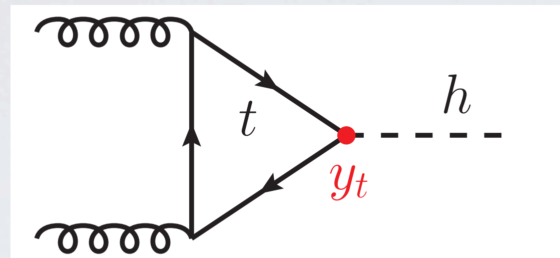
PHYSICS WITH TOP QUARKS

- Higgs physics:



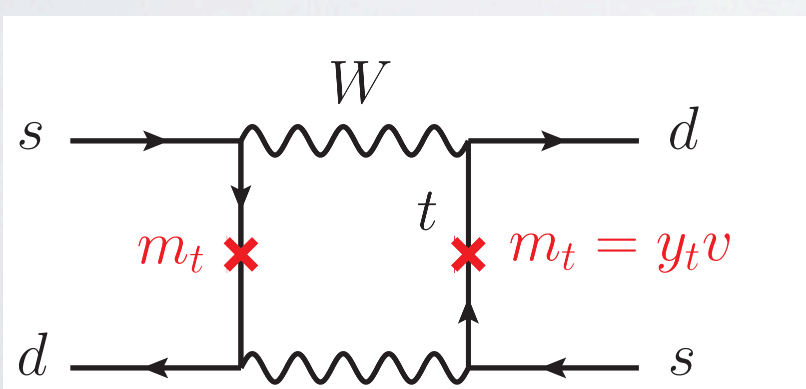


Top quark effects on Higgs mass, production, decay.

What is the mechanism of electroweak symmetry breaking?

$$\mathcal{L}_y = -y_q\, \overline{q}_L (v + h) q_R$$

- Flavor physics, flavor violation in down-quark sector:

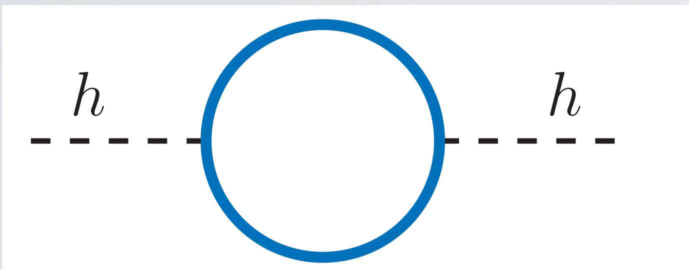


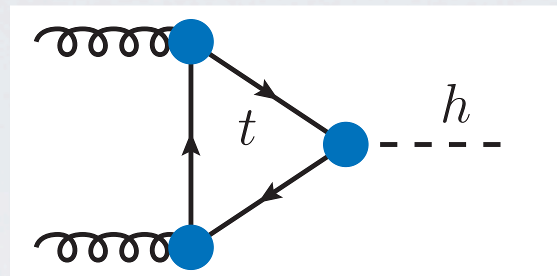
Top mass drives quark mixing, breaks flavor symmetries.

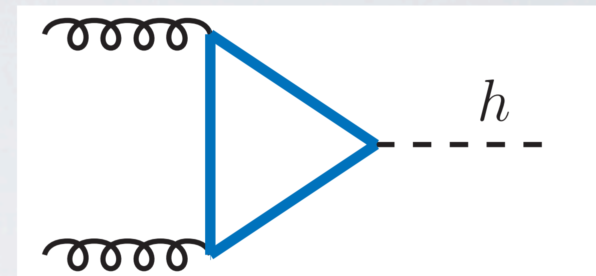
What is the source of flavor breaking?

NEW PHYSICS WITH TOP QUARKS

- Higgs physics:



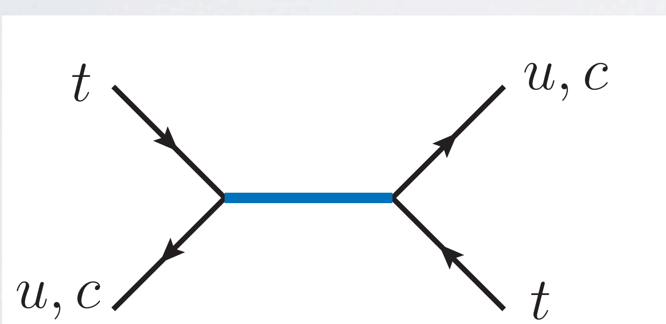


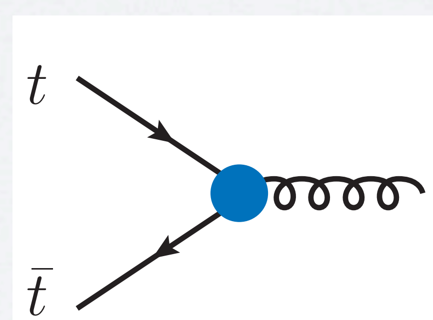


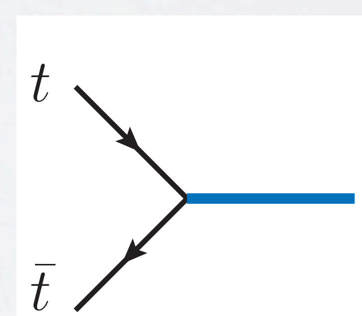
What is the mechanism of electroweak symmetry breaking?

Connection?

- Flavor physics, flavor violation in up-quark sector?



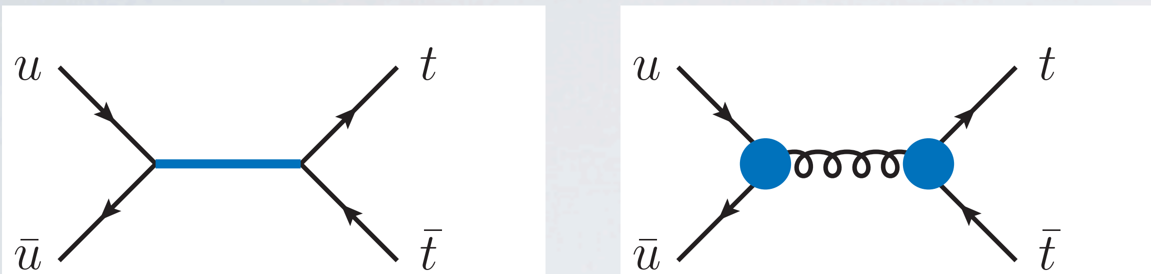




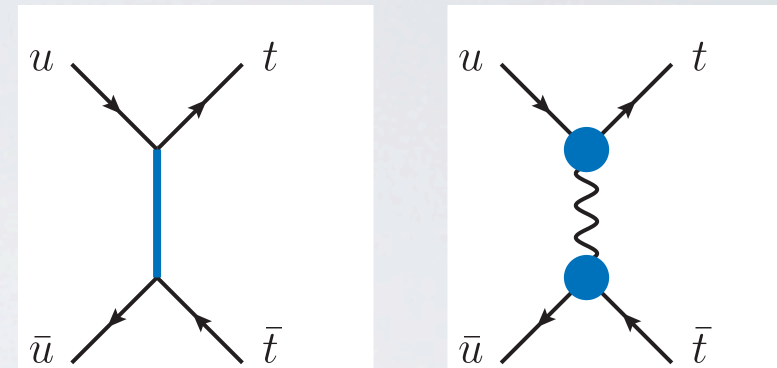
What is the source of flavor breaking?

NEW PHYSICS IN TOP PAIR PRODUCTION

s-channel:

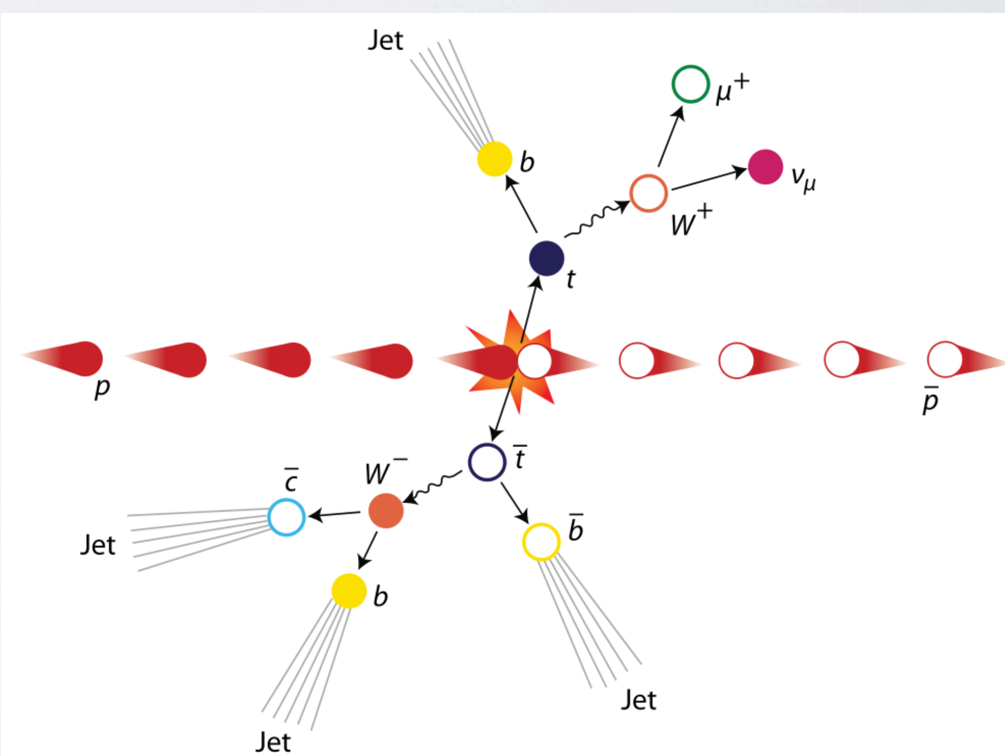


t-channel:

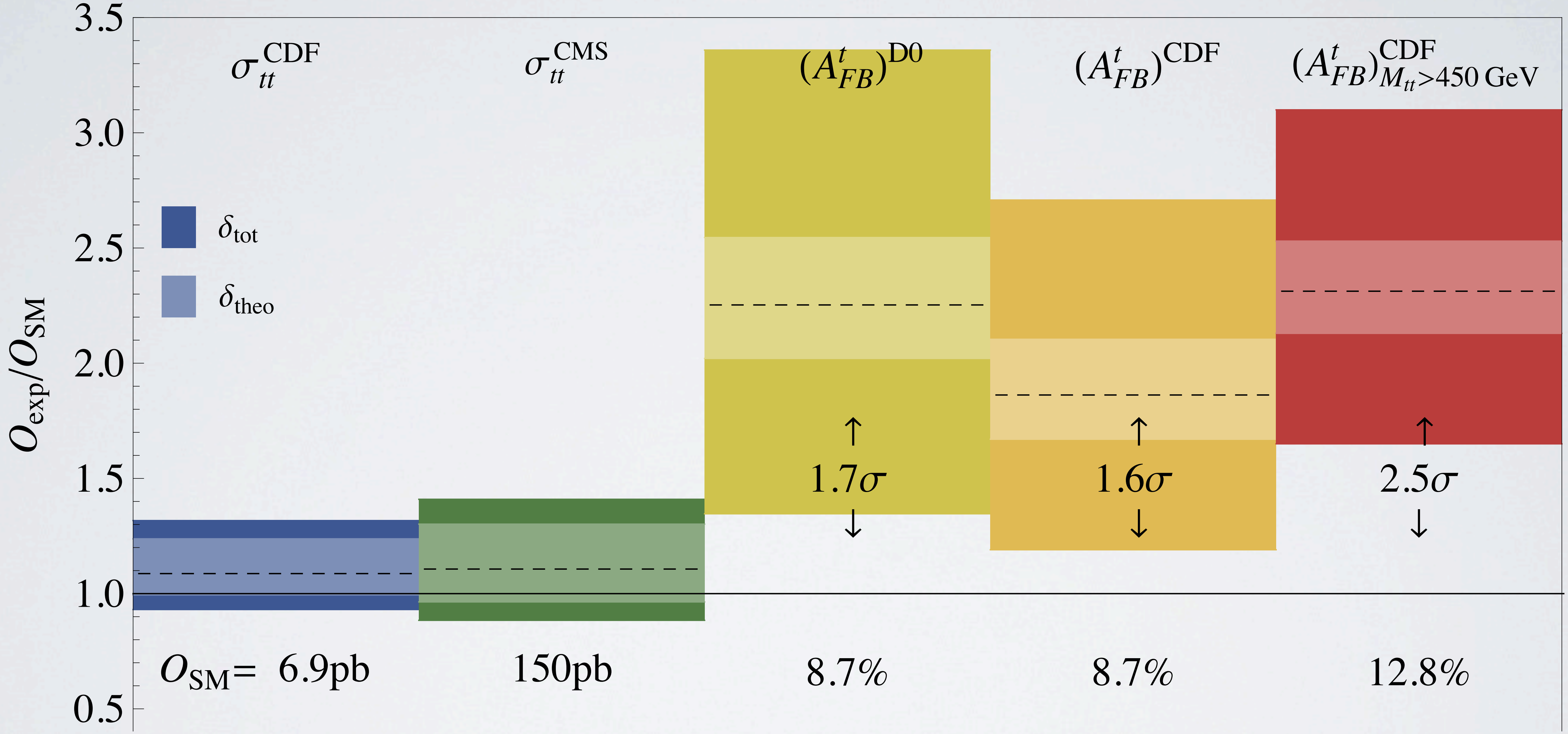


Probe new particles with couplings to top <u>and</u> up quarks via

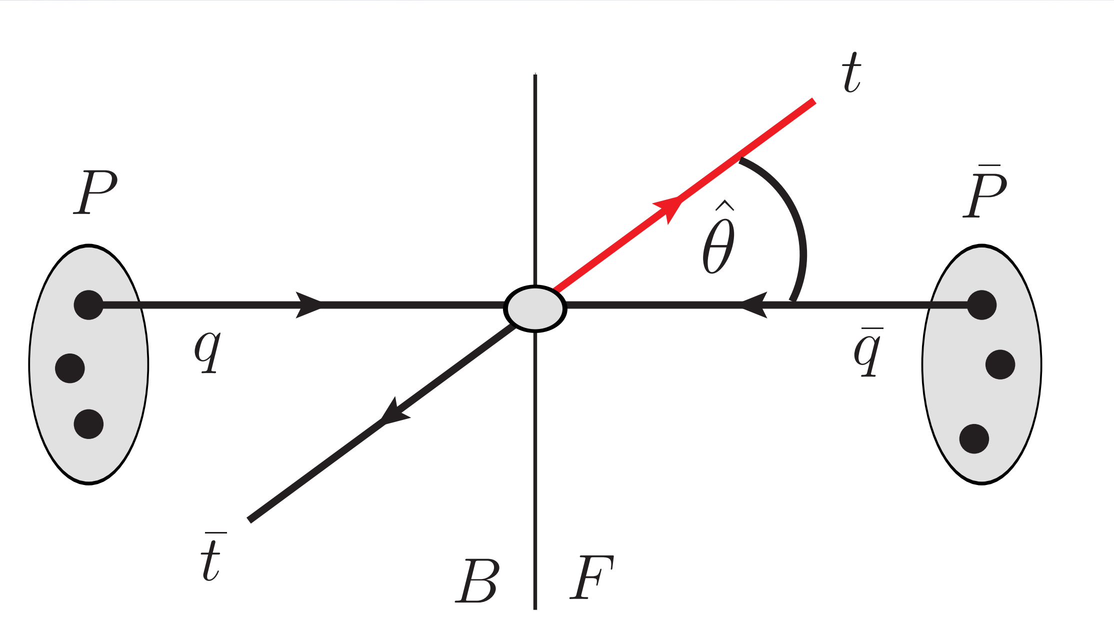
- Total cross section $\sigma_{t\bar{t}}$
- Distributions (invariant mass $M_{t\bar{t}}$)
- Charge asymmetries A_C^t
- Spin correlations
- Top decay products (leptons)
- Exclusive production of $t\bar{t} + j, h, \gamma$



TOP PAIR PRODUCTION IN JUNE 2012



TEVATRON FORWARD-BACKWARD ASYMMETRY

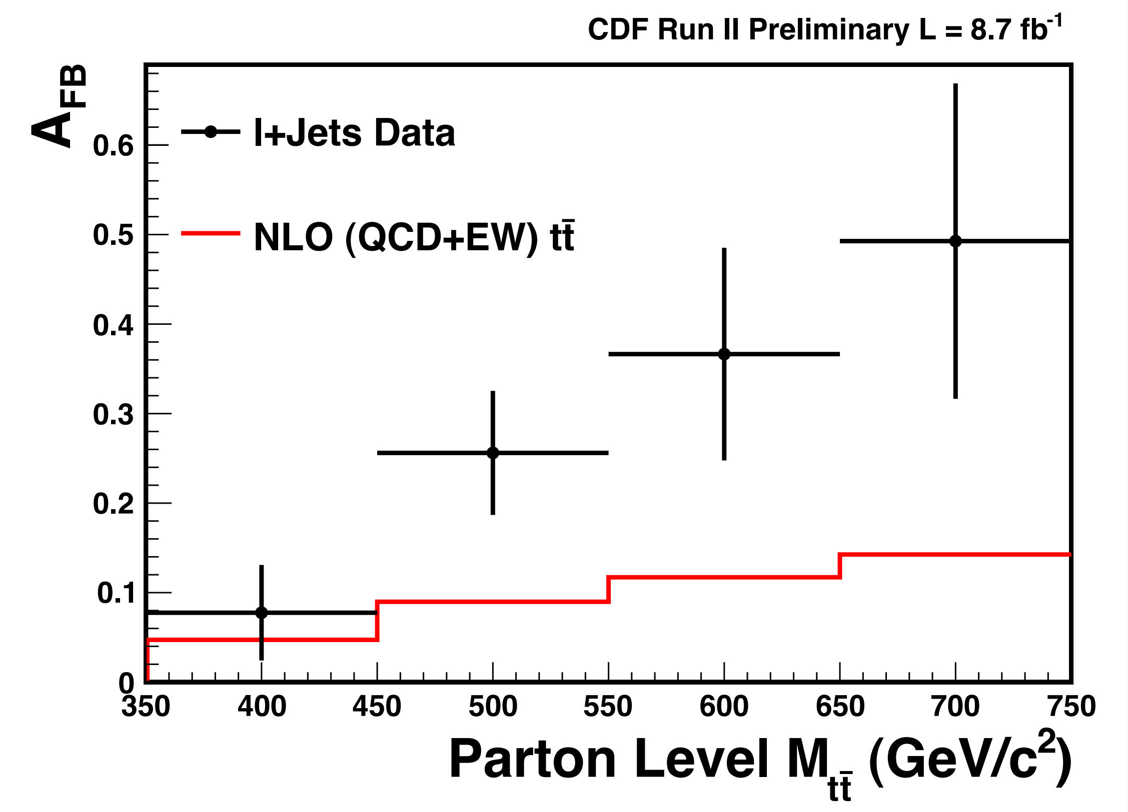


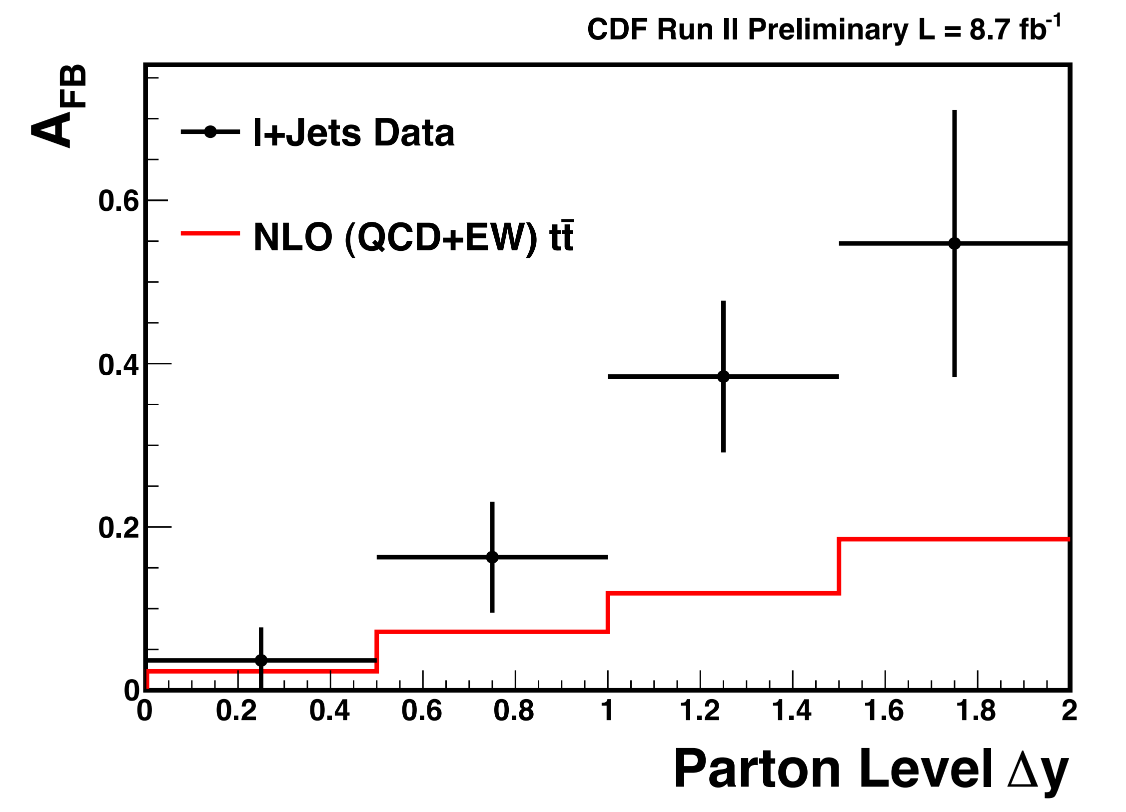
$$A^t_{\rm FB} = \frac{N(y_t > y_{\bar{t}}) - N(y_t < y_{\bar{t}})}{N(y_t > y_{\bar{t}}) + N(y_t < y_{\bar{t}})} \equiv A^t_C$$

$$A^{t,\rm CDF}_{\rm FB} = 16.2 \pm 4.7\%$$ [CDF, note 10807, 8.7fb^-1]

$$A^{t,\rm D0}_{\rm FB} = 19.6 \pm 6.5\%$$ [D0, PRD84(2011)112055, 5.4fb^-1]

Excess over QCD prediction at high $M_{t\bar{t}}$ and $\Delta y = y_t - y_{\bar{t}}$:



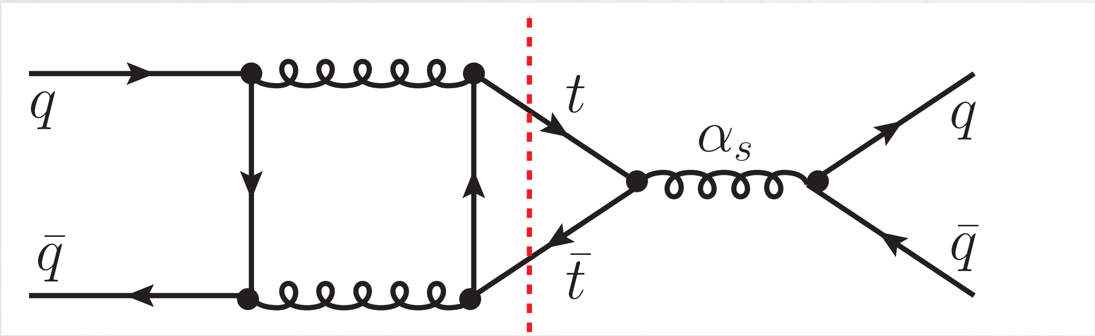


CHARGE ASYMMETRY IN THE STANDARD MODEL

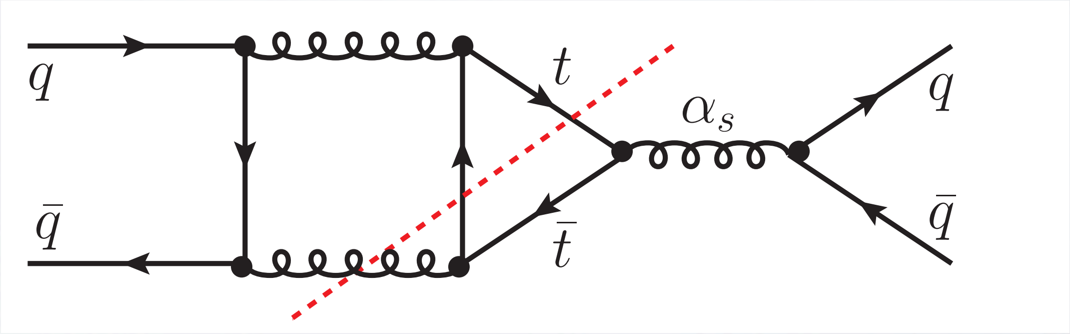
$$A_C^t = \frac{\int_0^1 d\cos\theta\, \sigma_a(\cos\theta)}{\sigma_s} \qquad \sigma_a(\cos\theta) = \sigma^{t\bar{t}}(\cos\theta) - \sigma^{\bar{t}t}(\cos\theta)$$

QCD: charge asymmetry at NLO

virtual: $\sigma_a > 0$



real: $\sigma_a < 0$



$$A_C^t = (7.24^{+1.06}_{-0.72})\%_{\text{NNLOappr}} \cdot 1.22_{\text{EW}}$$

[Ahrens et al., PRD 84 (2011) 074004]
[Hollik, Pagani, PRD 84 (2011) 093003]

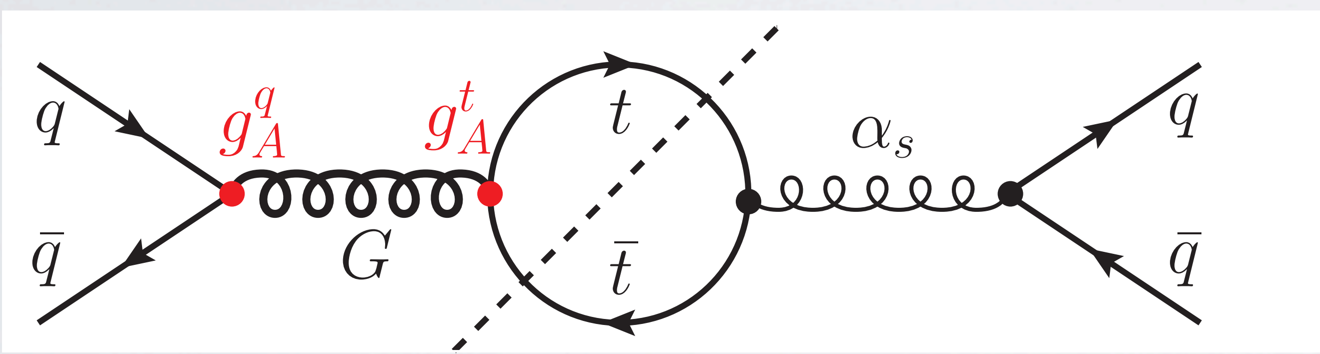
$$A_C^t(M_{t\bar{t}} > 450\text{GeV}) = (10.8^{+1.7}_{-0.9})\%_{\text{NNLOappr}} \cdot 1.23_{\text{EW}}$$

Electroweak contributions: $\mathcal{O}(20\%)$

MASSIVE GLUONS IN TOP PAIR PRODUCTION

Strong couplings to top quarks in models of

- warped extra dimensions (Kaluza-Klein gluons): $g_V^q\,, g_{V,A}^t$
- technicolor (colorons): $g_V^q\,, g_V^t$
- chiral color (axigluons): g_A^q, g_A^t ...



$$\mathcal{L} = i g_s \bar{q}\, \gamma^\mu T^a (g_V^q + \gamma_5 g_A^q)\, q$$

Tree-level contributions to top-quark pair production

$t\bar{t}$ symmetric: $\sigma_s^{\mathrm{INT}} \sim \alpha_s^2\, g_V^q g_V^t \dfrac{1}{M_{t\bar{t}}^2 - M_G^2}$ $\quad \sigma_s^{\mathrm{NP}} \sim \alpha_s^2\, (g_{V,A}^q)^2 (g_{V,A}^t)^2 \dfrac{M_{t\bar{t}}^2}{(M_{t\bar{t}}^2 - M_G^2)^2}$

$t\bar{t}$ asymmetric: $\sigma_a^{\mathrm{INT}} \sim \alpha_s^2\, g_A^q g_A^t \dfrac{1}{M_{t\bar{t}}^2 - M_G^2}$ $\quad \sigma_a^{\mathrm{NP}} \sim \alpha_s^2\, g_V^q g_A^q\, g_V^t g_A^t \dfrac{M_{t\bar{t}}^2}{(M_{t\bar{t}}^2 - M_G^2)^2}$

CONSTRAINTS ON MASSIVE COLOR OCTETS

Model-dependent:

[Bai et al., JHEP 1103 (2011) 003][Haisch, SW, JHEP 1108 (2011) 088]

- Flavor precision observables (flavor non-universal couplings)

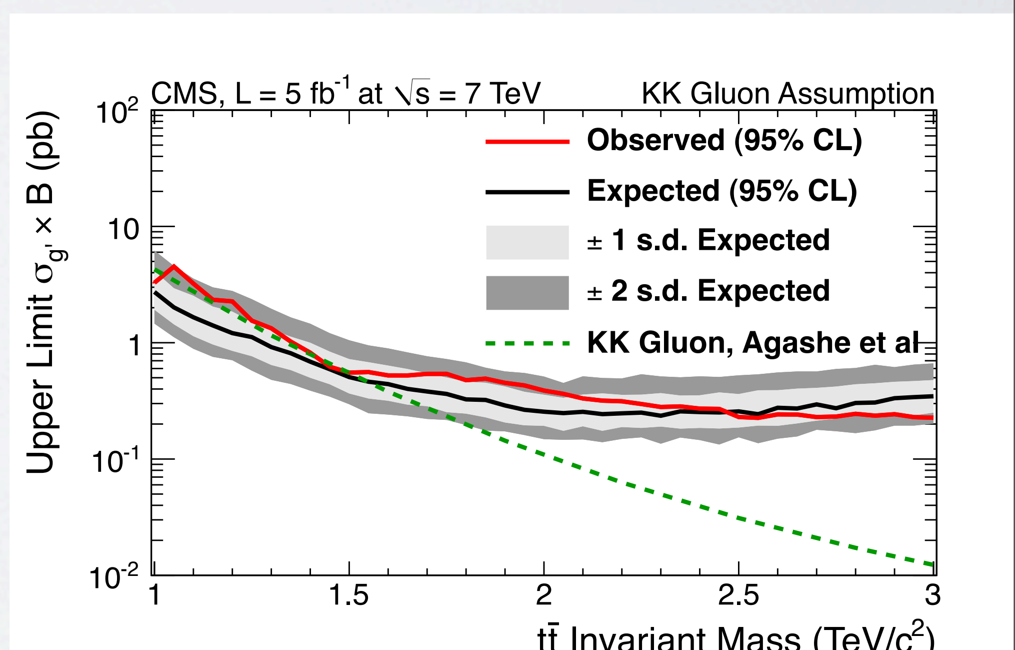
Light new bosons ($M_G < 1\,\mathrm{TeV}$): LEP and Tevatron

[Haisch, SW, JHEP 1108 (2011) 088][Hill, Zhang, PRD 51 (1995) 3563]

- Electroweak precision observables Zbb, oblique corrections
- Top pair cross section and Mtt spectrum
- Paired dijet resonances [CMS PAS EXO-11-016]

Heavy new bosons ($M_G > 1\,\mathrm{TeV}$): LHC

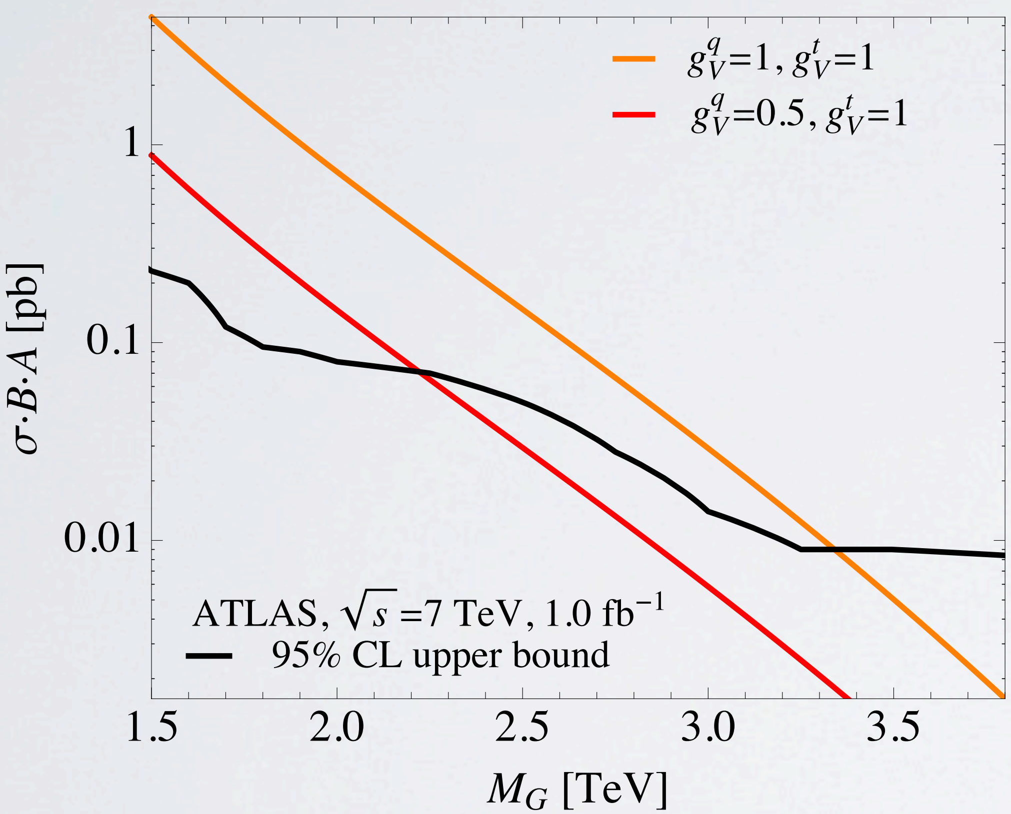
- Dijet resonance searches
- Dijet angular distributions
- Top pair cross section
- Resonance searches in Mtt spectrum

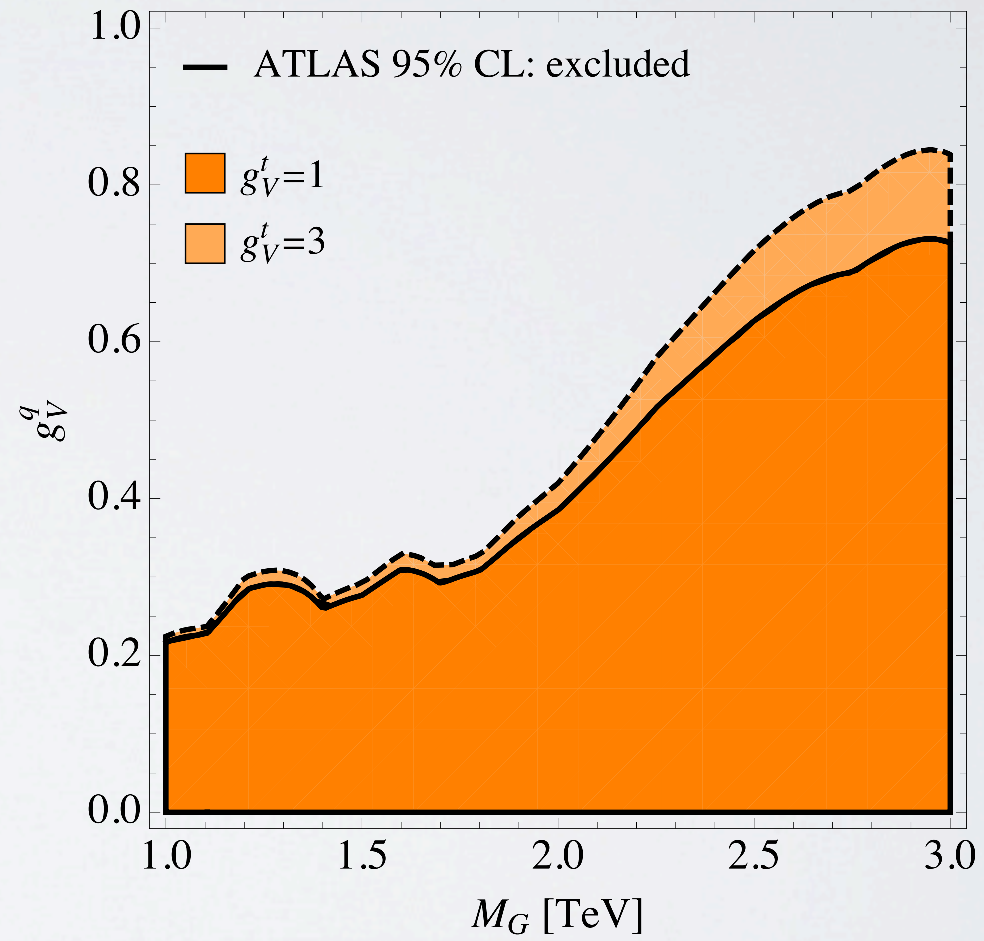


DIJET RESONANCE SEARCHES

Constraints on the production of a narrow jj resonance:

$$\sigma(pp \to G) \cdot \mathcal{B}(G \to q\bar{q}) \sim [(g_V^q)^2 + (g_A^q)^2]$$





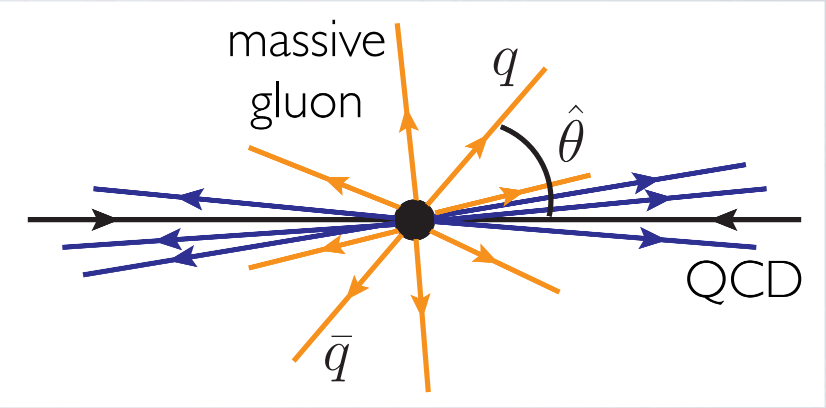
[ATLAS, PLB 708 (2012) 37][CMS, PLB 704 (2011) 123, 1fb^-1]

Evade dijet bounds on effects in tt̲ production by rescaling:

$$g_{V,A}^q \to \xi \cdot g_{V,A}^q, \;\; g_{V,A}^t \to g_{V,A}^t/\xi$$

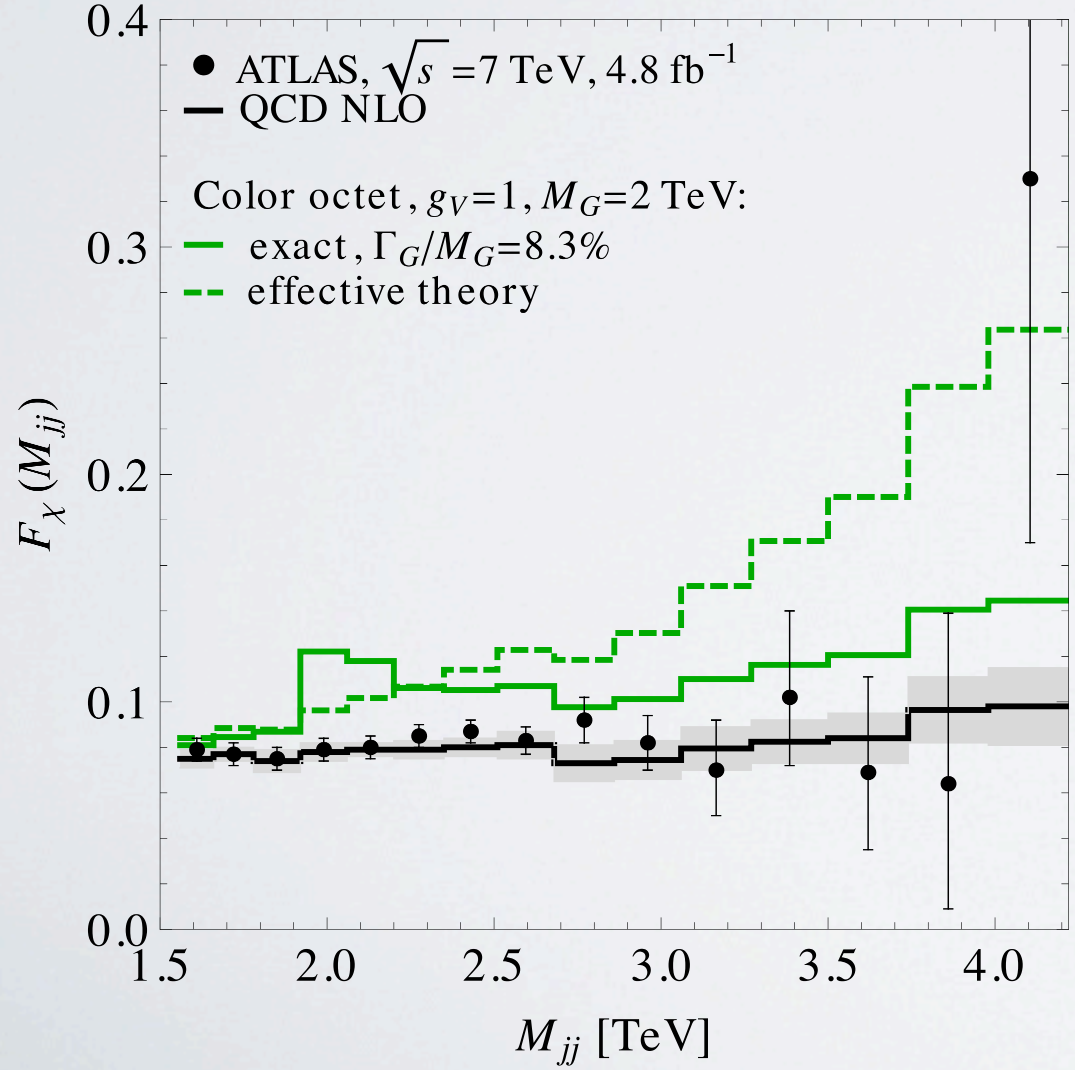
DIJET ANGULAR DISTRIBUTION

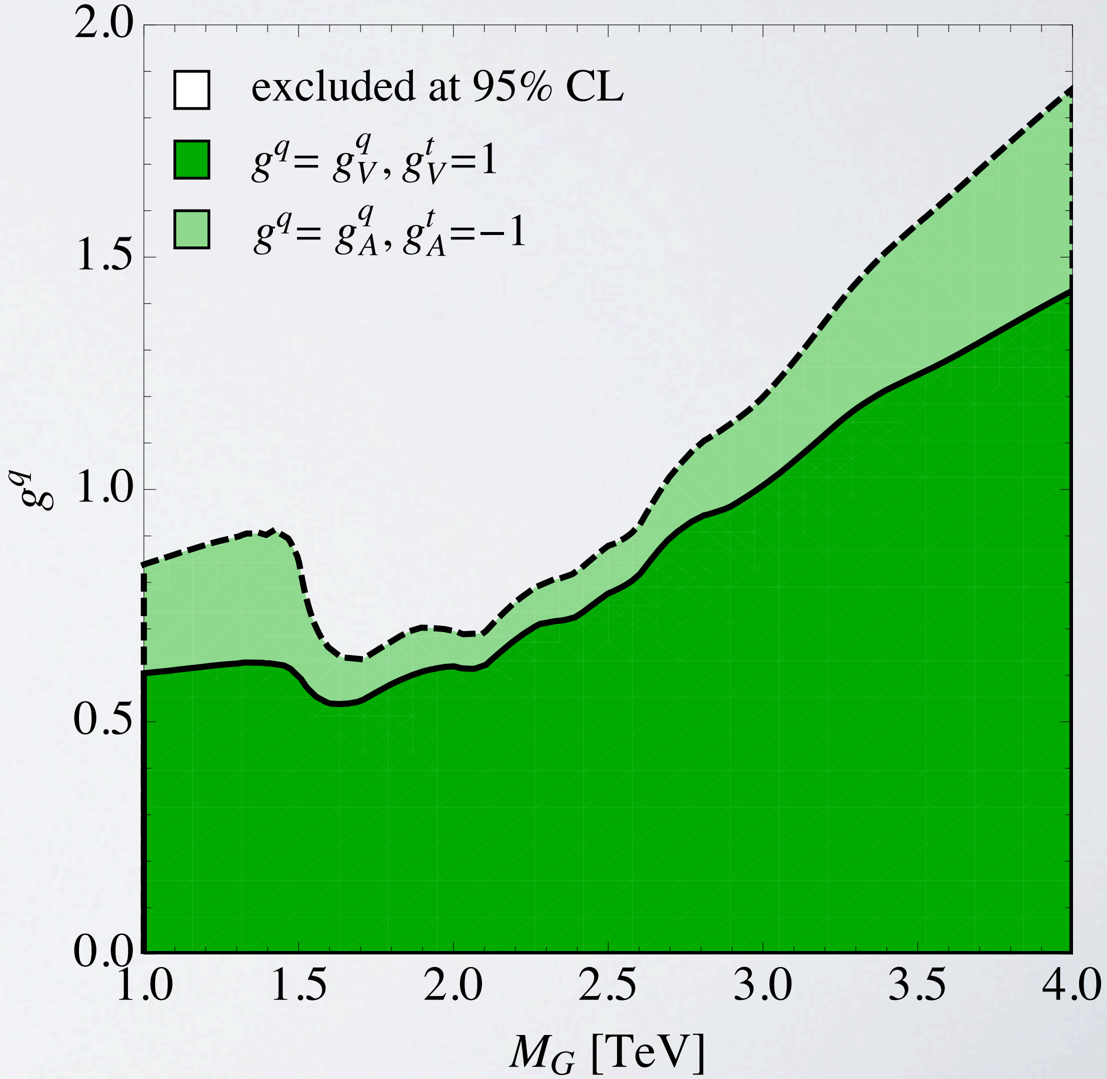
Dijet excess in central region:



$$F_\chi(M_{jj}) = \frac{\sigma(\chi < 3.3, M_{jj})}{\sigma(\chi < 30, M_{jj})}, \ \chi = \frac{1 + |\cos\theta|}{1 - |\cos\theta|}$$

[ATLAS-CONF-2012-038, 4.8fb^-1][CMS-EXO-11-017, 2.2fb^-1]



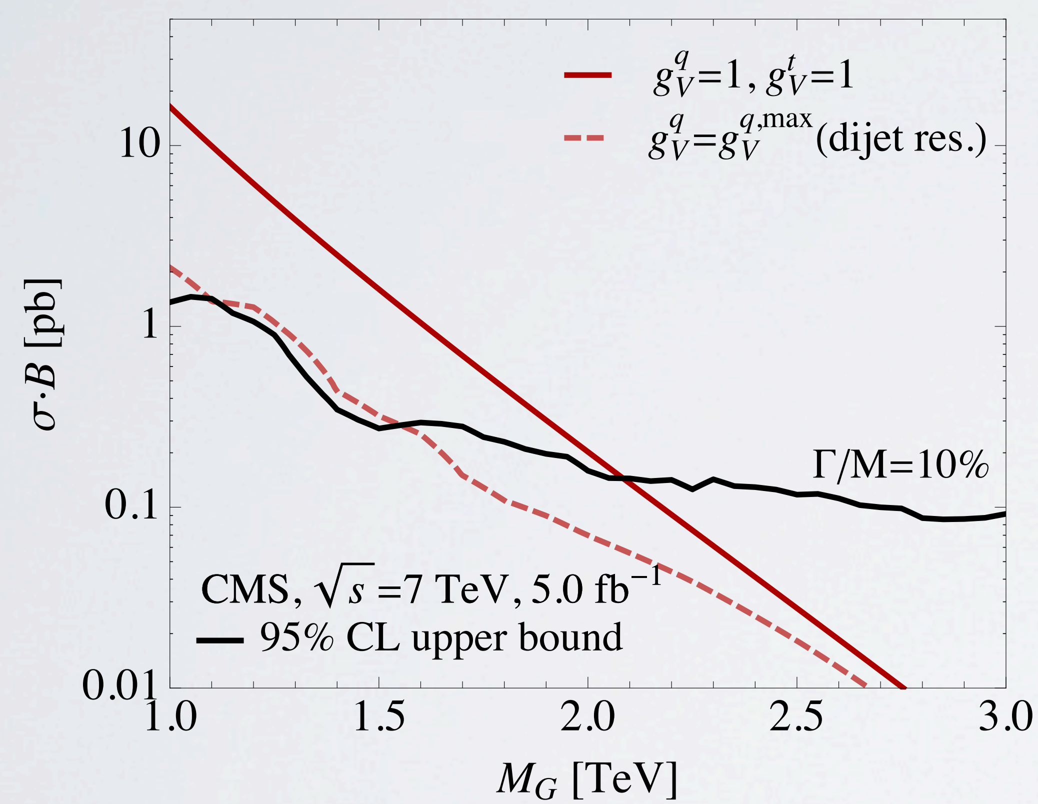


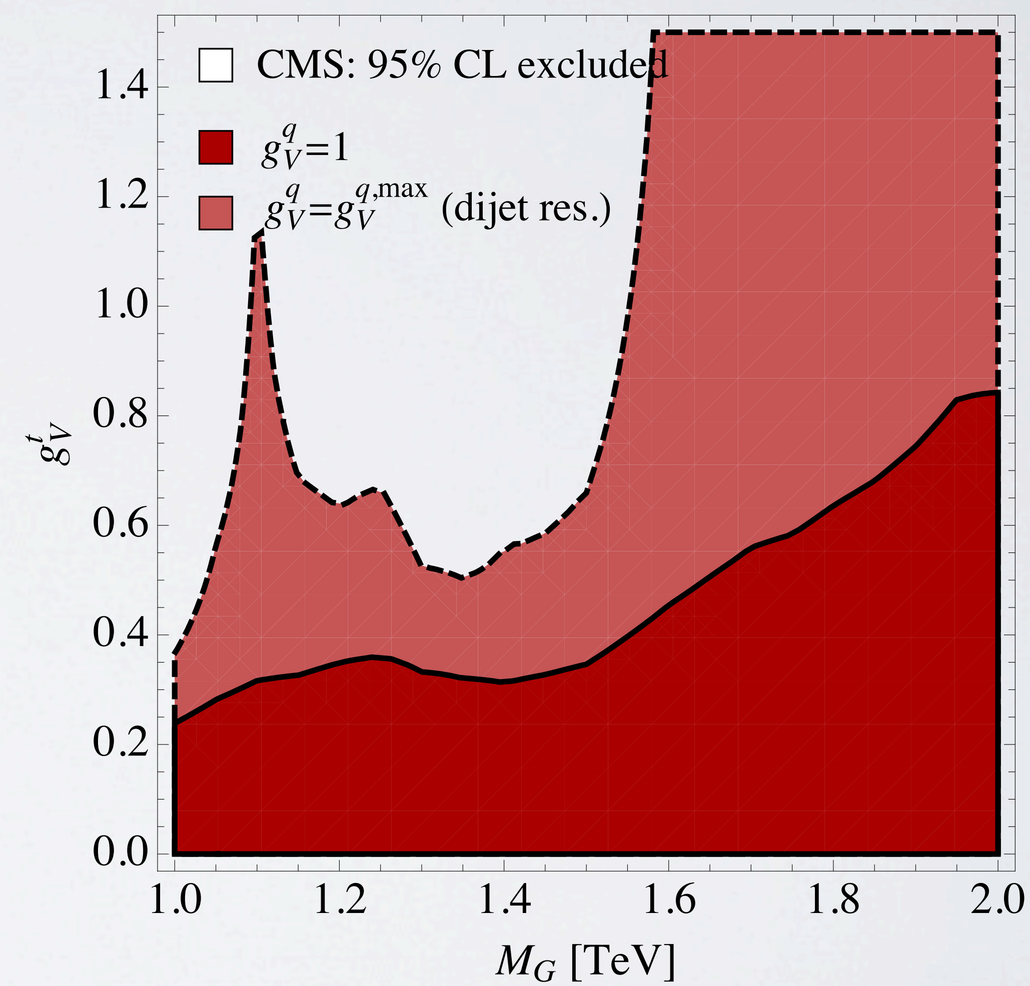
TOP-ANTITOP RESONANCE SEARCHES

Constraints on the production of a narrow tt̲ resonance:

$$\sigma(pp \to G) \cdot \mathcal{B}(G \to t\bar{t}) \sim [(g_V^t)^2 + (g_A^t)^2] \qquad (g_{V,A}^q \gtrsim g_{V,A}^t)$$

$$\sim [(g_V^q)^2 + (g_A^q)^2] \qquad (g_{V,A}^q \ll g_{V,A}^t)$$





[CMS-EXO-11-006, 5fb^-1, hadronic. Courtesy of S. Rappoccio]

[ATLAS, arXiv:1205.5371, 2.05fb^-1, l+jets]

$\sigma \cdot \mathcal{B}$ becomes insensitive to $g_{V,A}^t$ for small $g_{V,A}^q$.
→No constraints for $M_G \gtrsim 1.6\,\mathrm{TeV}$, if $g_{V,A}^q$ respects dijet bounds.

TOP-ANTITOP TOTAL CROSS SECTION

- Precision QCD predictions

[Ahrens et al., PRD 84 (2011) 074004, rescaled]

Tevatron: $\sigma_{t\bar{t}}^{\rm QCD} = 6.90\,^{+0.40}_{-0.74}\,^{+0.50}_{-0.40}\,\rm pb$ LHC7: $\sigma_{t\bar{t}}^{\rm QCD} = 150\,^{+18}_{-19}\,^{+13}_{-12}\,\rm pb$

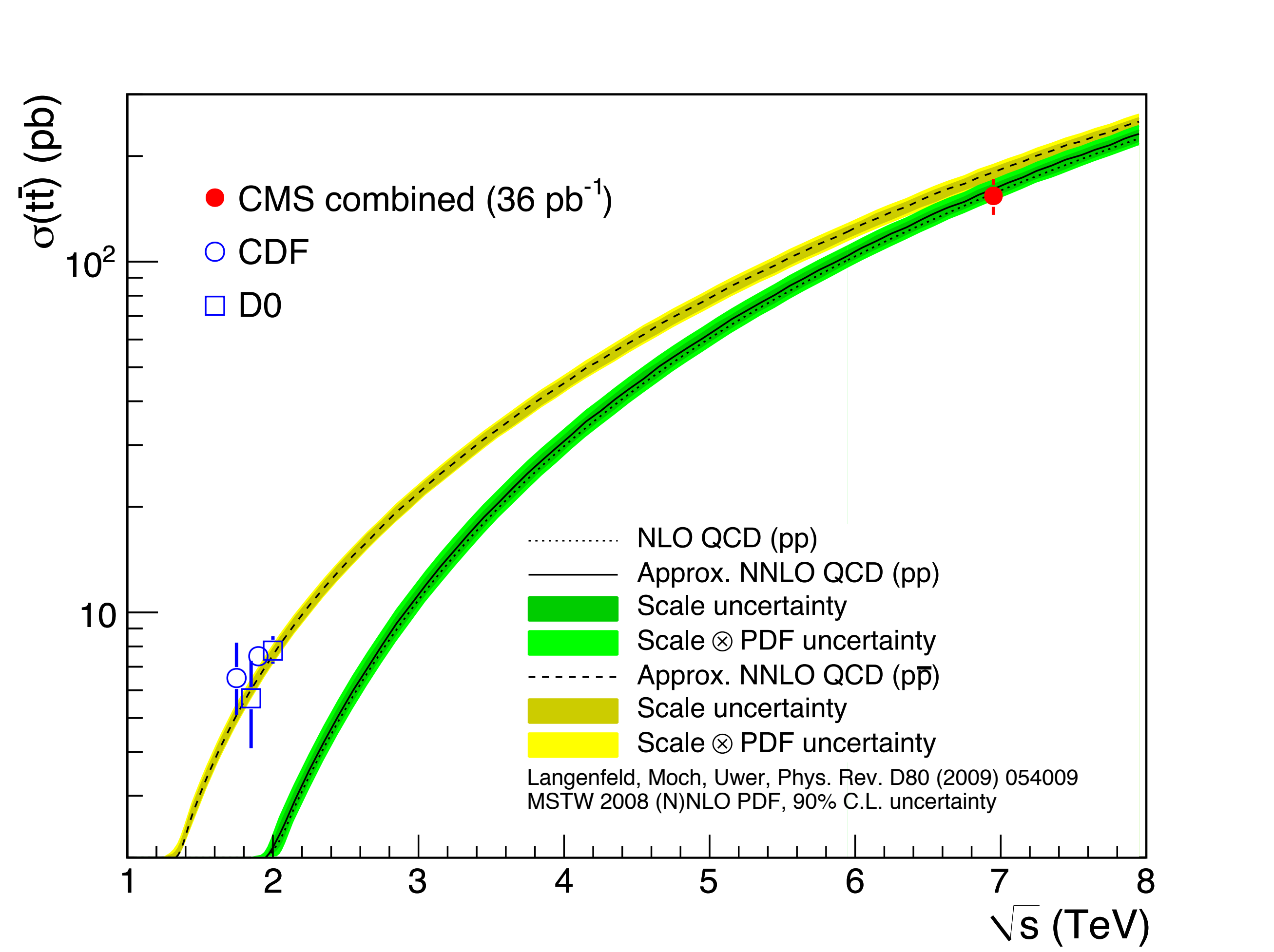
- And precision measurements

$$\sigma_{t\bar{t}}^{\rm CDF}(\sqrt{s} = 1.96{\rm TeV}) = 7.50 \pm 0.48\,\rm pb$$

$$\sigma_{t\bar{t}}^{\rm CMS}(\sqrt{s} = 7{\rm TeV}) = 165.8 \pm 13.3\,\rm pb$$

[CDF-CONF-9913,<4.6fb^-1][D0, PLB 704 (2011) 403, 5.4fb^-1, lj+ll]

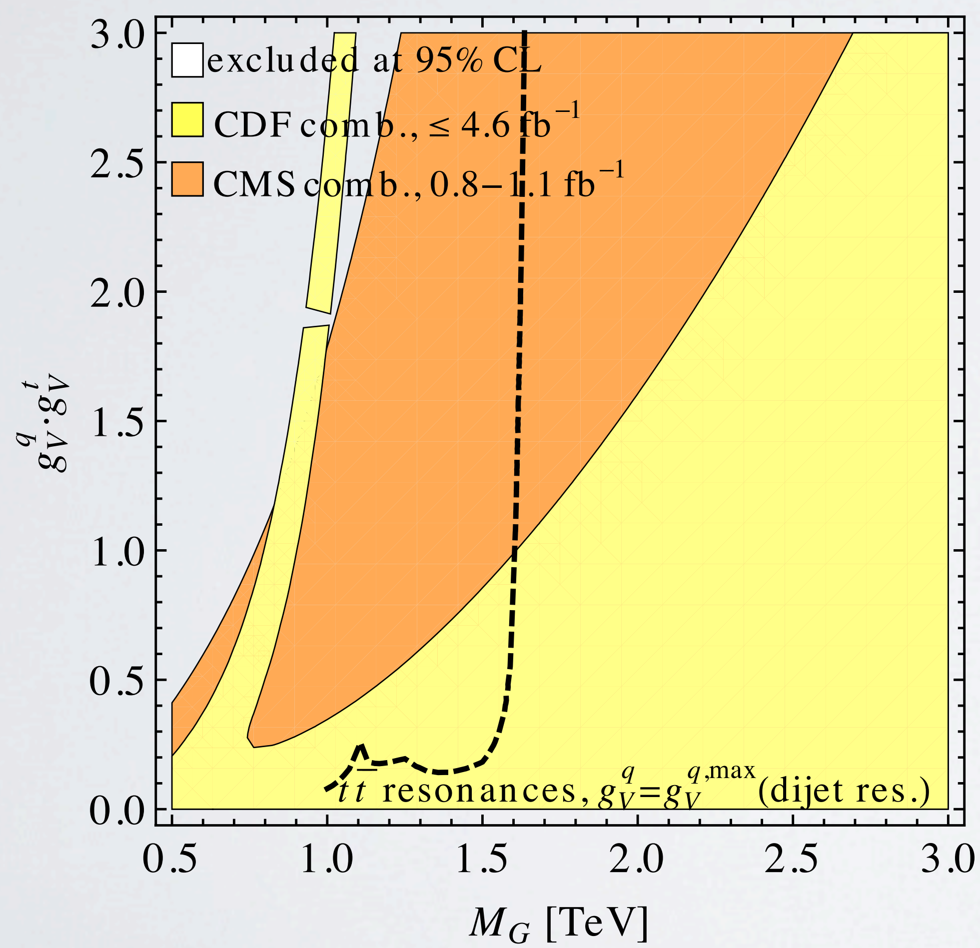
[CMS PAS TOP-11-024,<1.1fb^-1][ATLAS-CONF-2012-024,<1.0fb^-1]



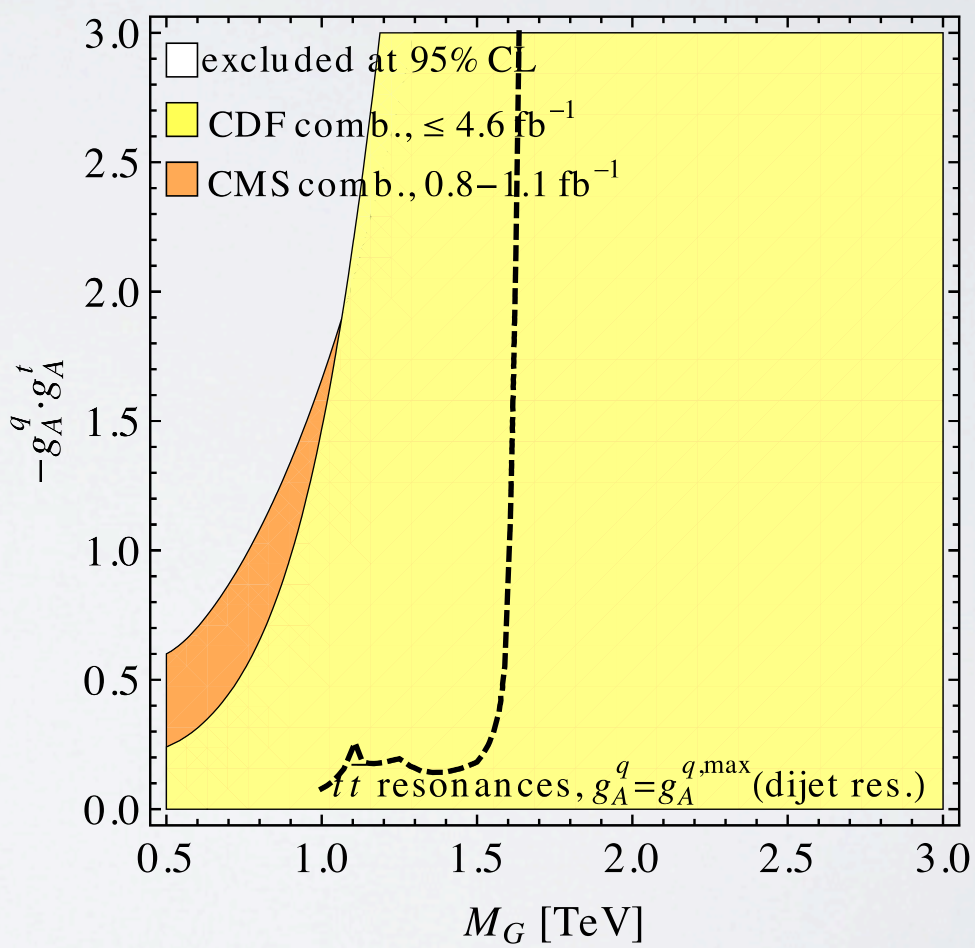
TOTAL CROSS SECTION: CONSTRAINTS

- Tevatron: $q\bar{q}$ dominant $\longrightarrow$ good sensitivity to massive gluons
- LHC7: large gg background (no $gg \to G$ at tree level)

Vector couplings: interference w/ QCD

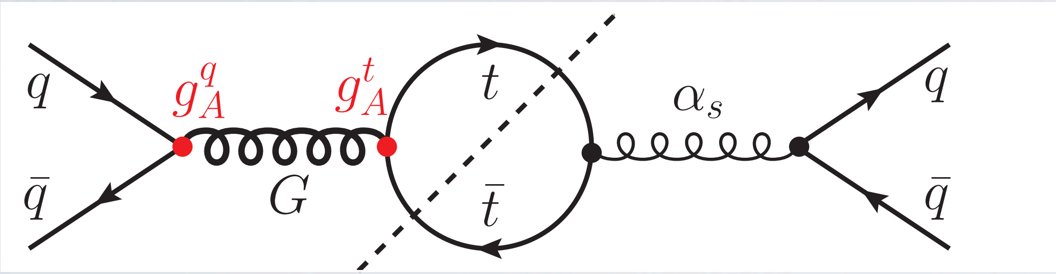


Axial-vector couplings: no interference

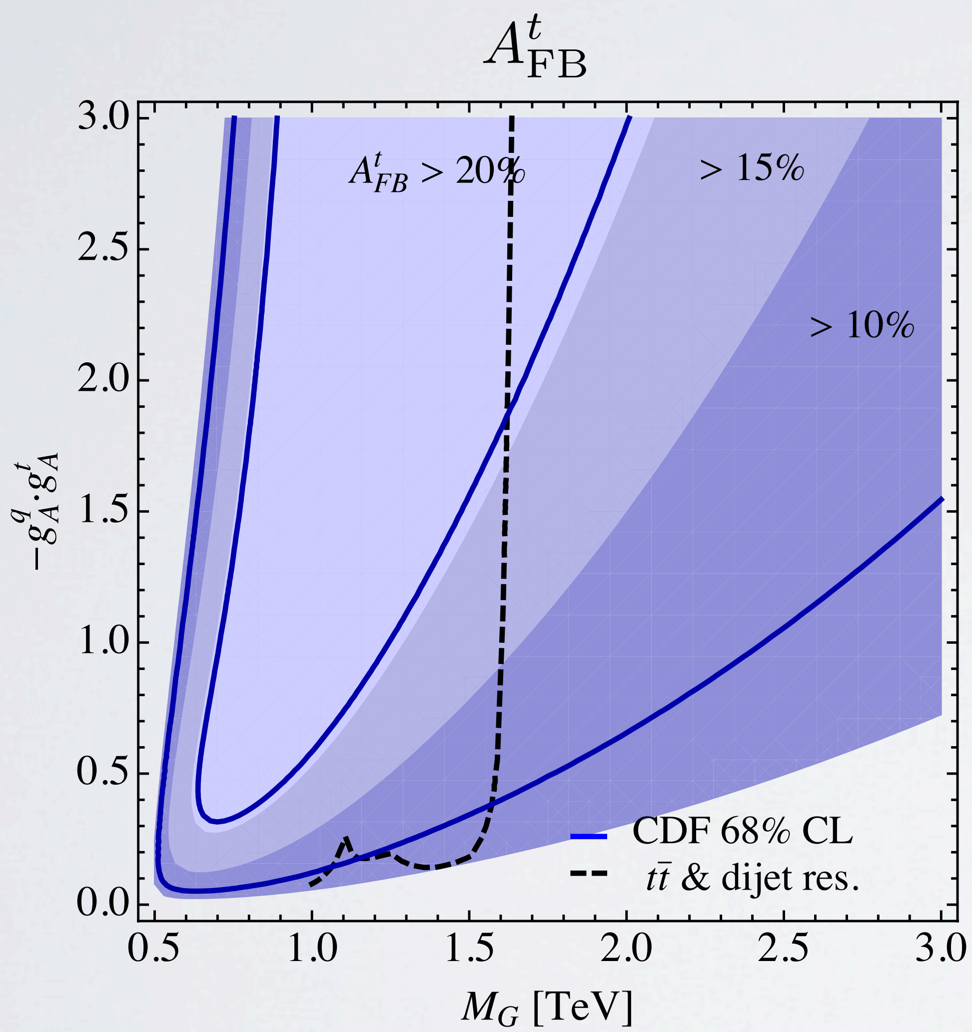


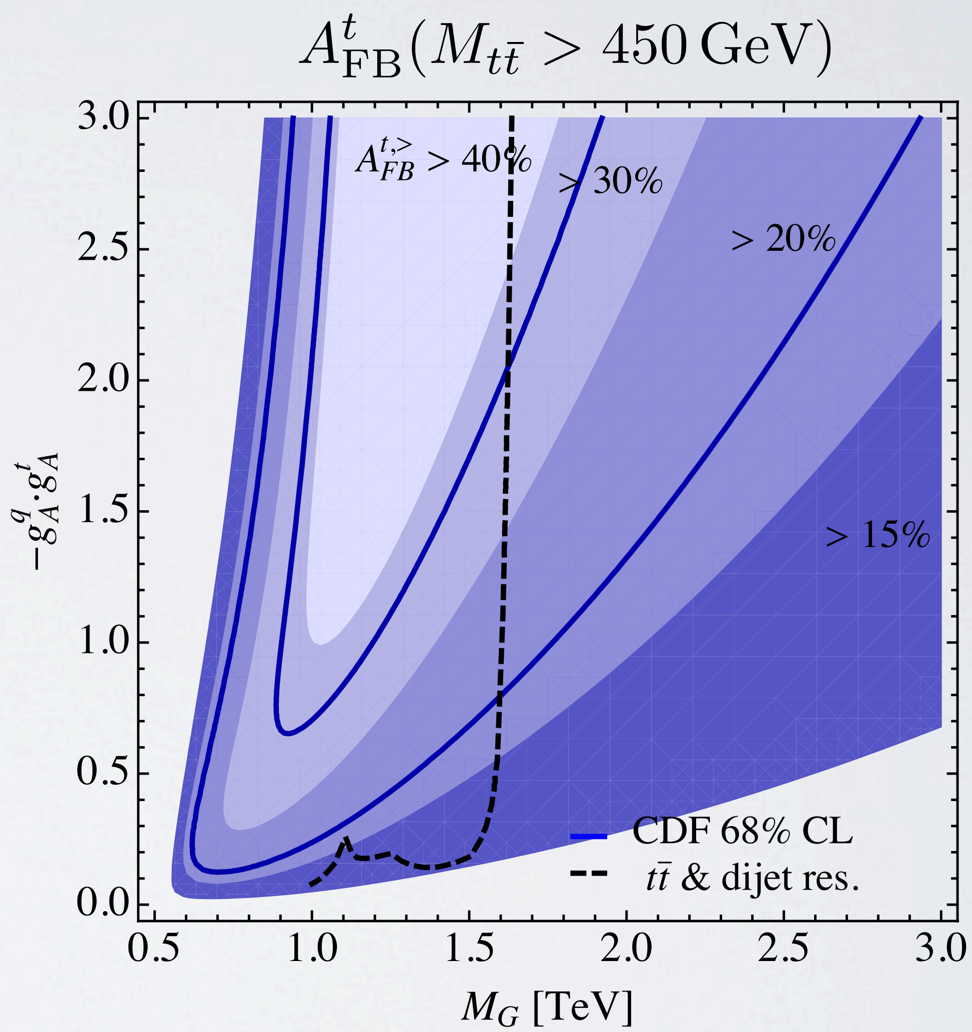
Constraints from tt resonance searches dominate for $M_G \lesssim 1.6\,\mathrm{TeV}$.

AXIGLUON EFFECTS ON TEVATRON ASYMMETRY



$$g_A^q \cdot g_A^t < 0 \to \sigma_a^{\rm INT} > 0$$





An axigluon with $M_G \sim 2\,{\rm TeV}$ and strong top couplings can accommodate the CDF measurement.

„BEAMWARD-CENTRAL" ASYMMETRY AT LHC

Boosted q in proton ⟶ more t than t̲ in beam direction.

$$A_C^y = \frac{N(|y_t| > |y_{\bar{t}}|) - N(|y_t| < |y_{\bar{t}}|)}{N(|y_t| > |y_{\bar{t}}|) + N(|y_t| < |y_{\bar{t}}|)} = \frac{\sigma_a(|y_t| > |y_{\bar{t}}|)}{\sigma_s} < A_C^t$$

$$A_C^{y,\mathrm{QCD}} = 1.15 \pm 0.06\,\%$$

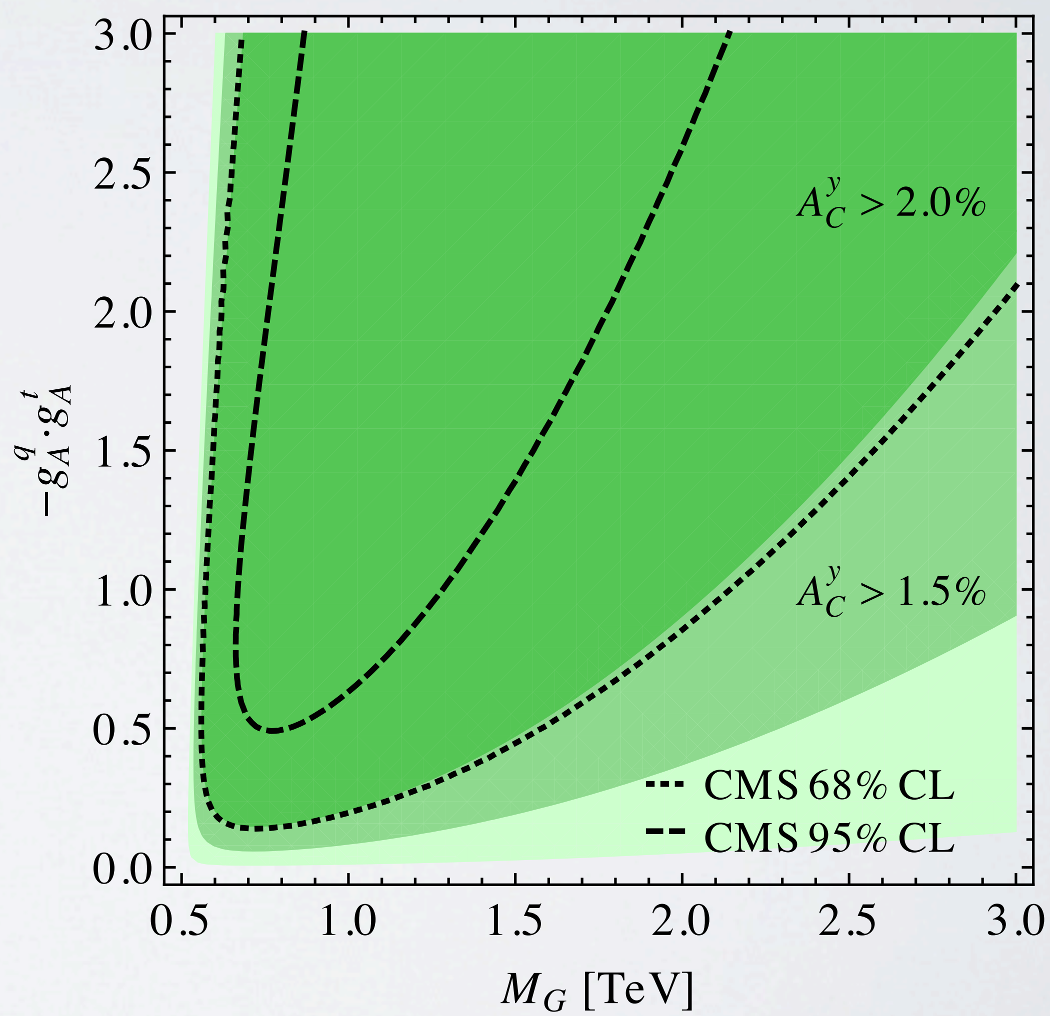
[Kühn, Rodrigo, JHEP 1201 (2012) 063]

$$A_C^{y,\mathrm{ATLAS}} = 2.9 \pm 1.8 \pm 1.4\,\%$$

[ATLAS-CONF-2012-057, lj (1.04fb^-1) + ll (4.7fb^-1) comb.]

$$A_C^{y,\mathrm{CMS}} = 0.4 \pm 1.0 \pm 1.2\,\%$$

[CMS-PAS-TOP-11-030, lj, 4.7fb^-1]



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$$A_C^{y,\mathrm{QCD}} = 1.15 \pm 0.06\,\%$$

[Kühn, Rodrigo, JHEP 1201 (2012) 063]

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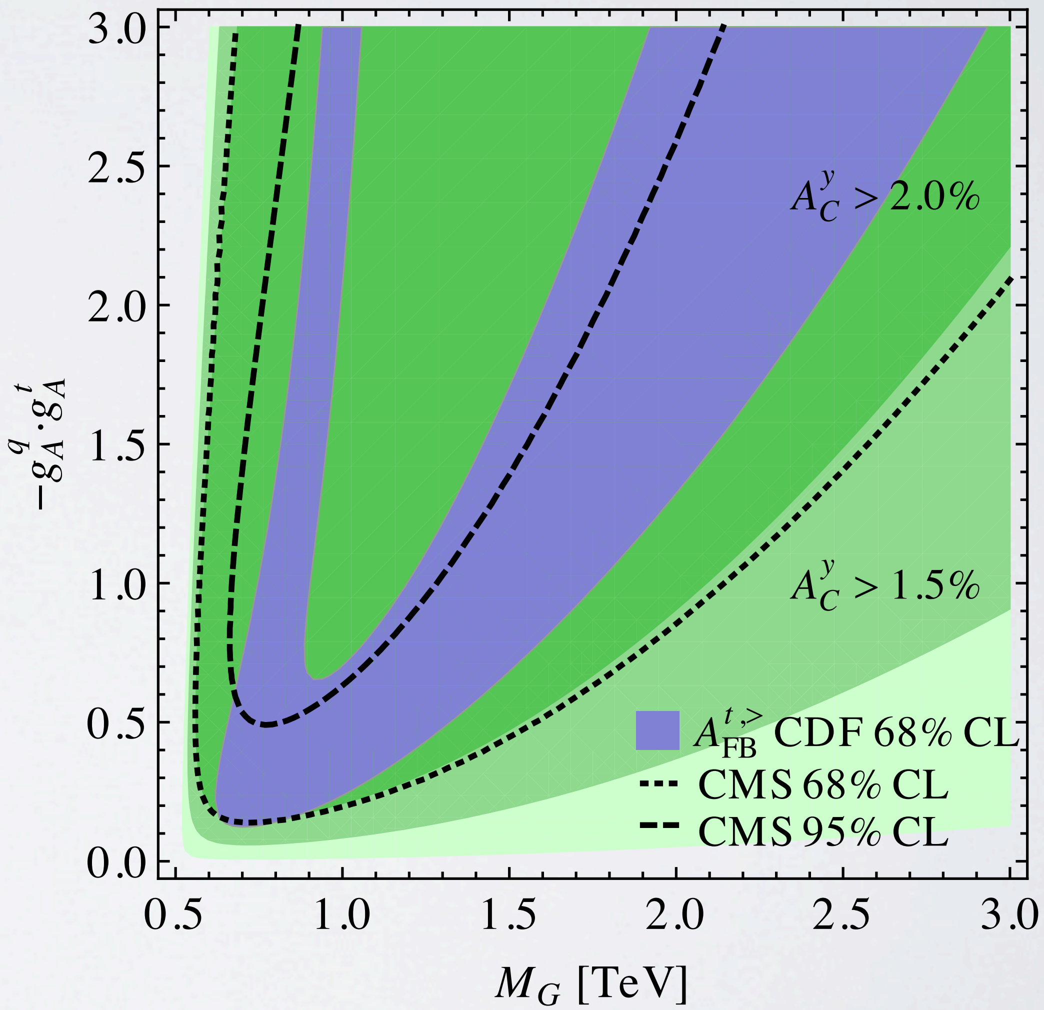
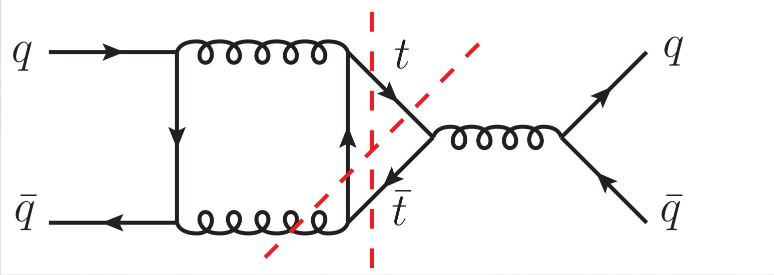


A_C^y does not (yet) rule out the axigluon solution to A_{FB}^t and $A_{\mathrm{FB}}^{t,>}$.

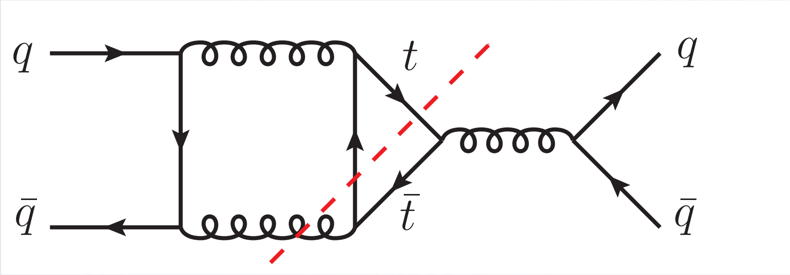
CHARGE ASYMMETRY WITH A JET HANDLE

Inclusive tt̲ + X: QCD asymmetry at NLO



virtual & real contributions

Exclusive tt̲ + jet: asymmetry at LO



separate access
to real contributions

Asymmetry in tt̲ + jet known to NLO.

[Dittmaier, Uwer, Weinzierl, Eur. Phys. J. C59 (2009) 625]
[Melnikov, Schulze, Nucl. Phys. B840 (2010) 129]

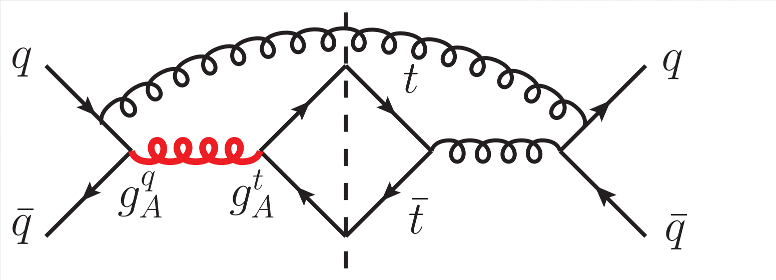
Tevatron: $A_C^{t,\mathrm{LO}} = -8\%$ $\quad A_C^{t,\mathrm{NLO}} = -2\%$

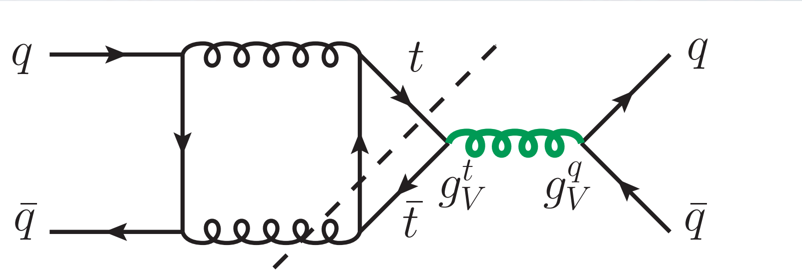
LHC8: $A_C^{y,\mathrm{LO}} = -0.5\%$

$(p_T^{j,\mathrm{cut}} = 20\,\mathrm{GeV})$

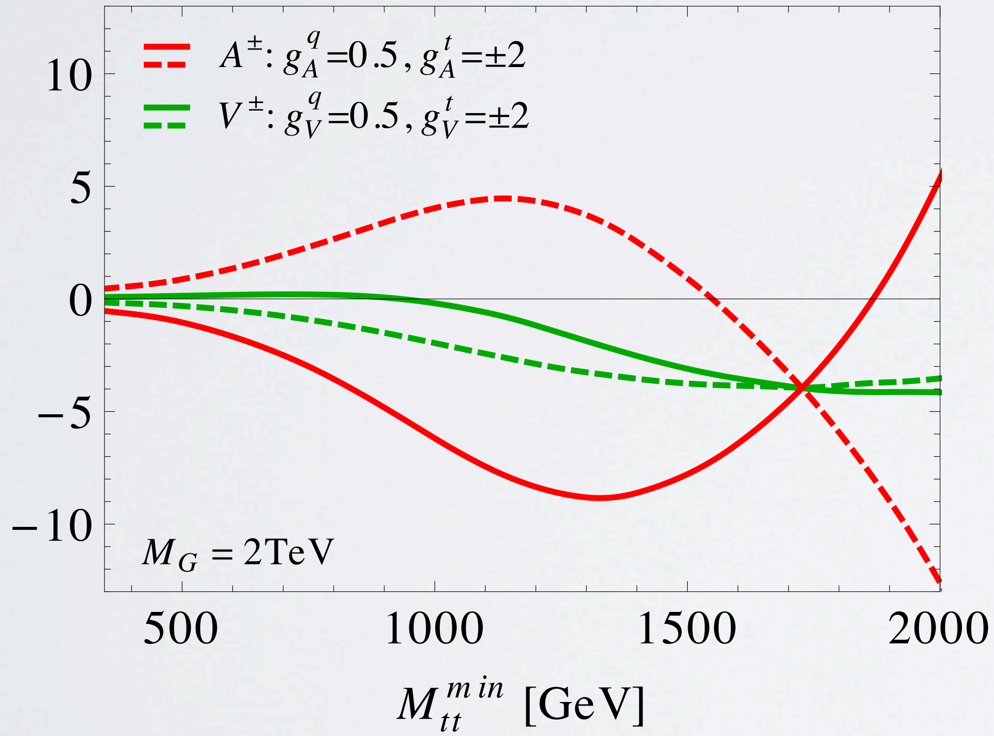
MASSIVE GLUONS IN TOP-PAIR PLUS JET

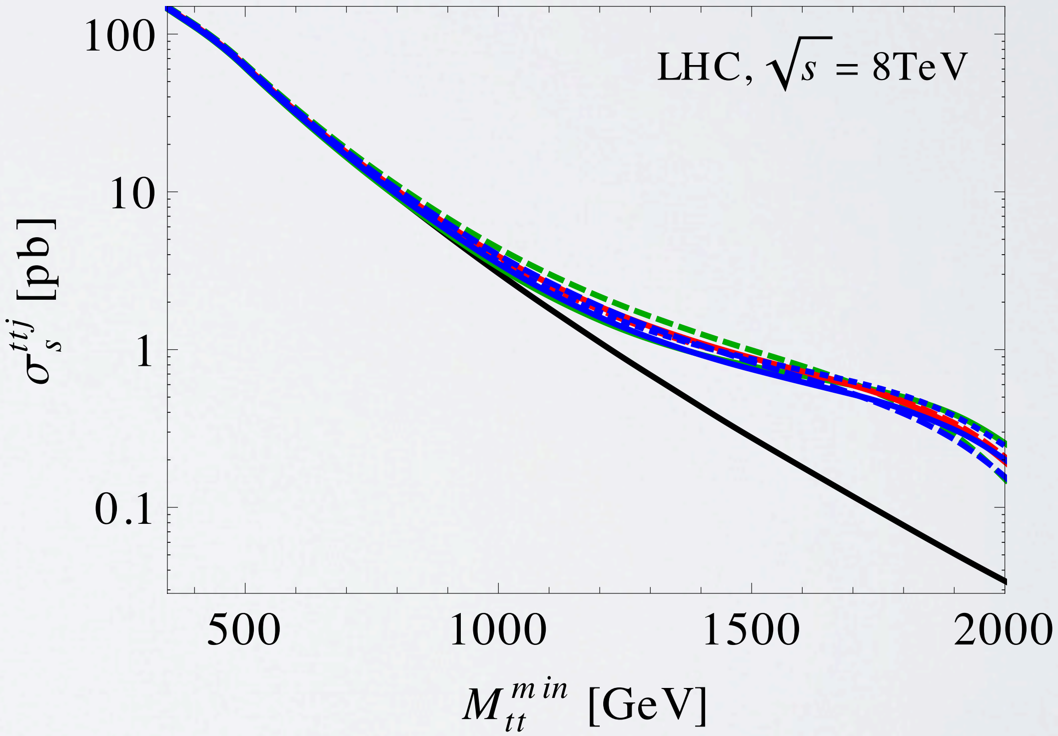
Axial-vector <u>and vector</u> contributions to asymmetry at LO:





A cut on $M_{t\bar{t}}$ enhances the sensitivity to massive resonances.



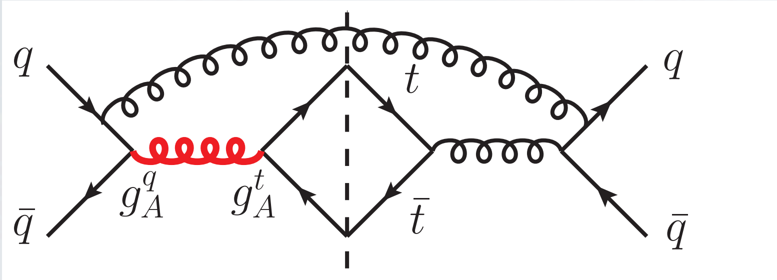


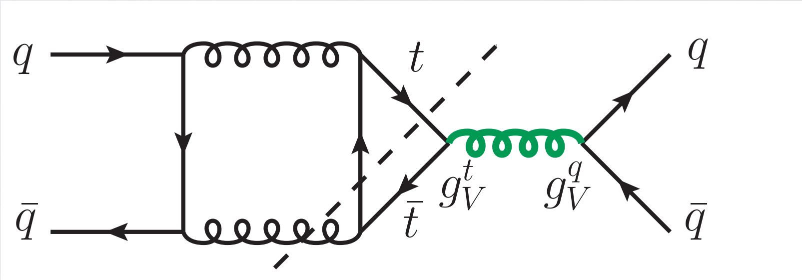
Disentangle vector and axial-vector effects via their spectra.

[Berge, SW, in preparation][Ferrario, Rodrigo, JHEP 1002 (2010) 051]

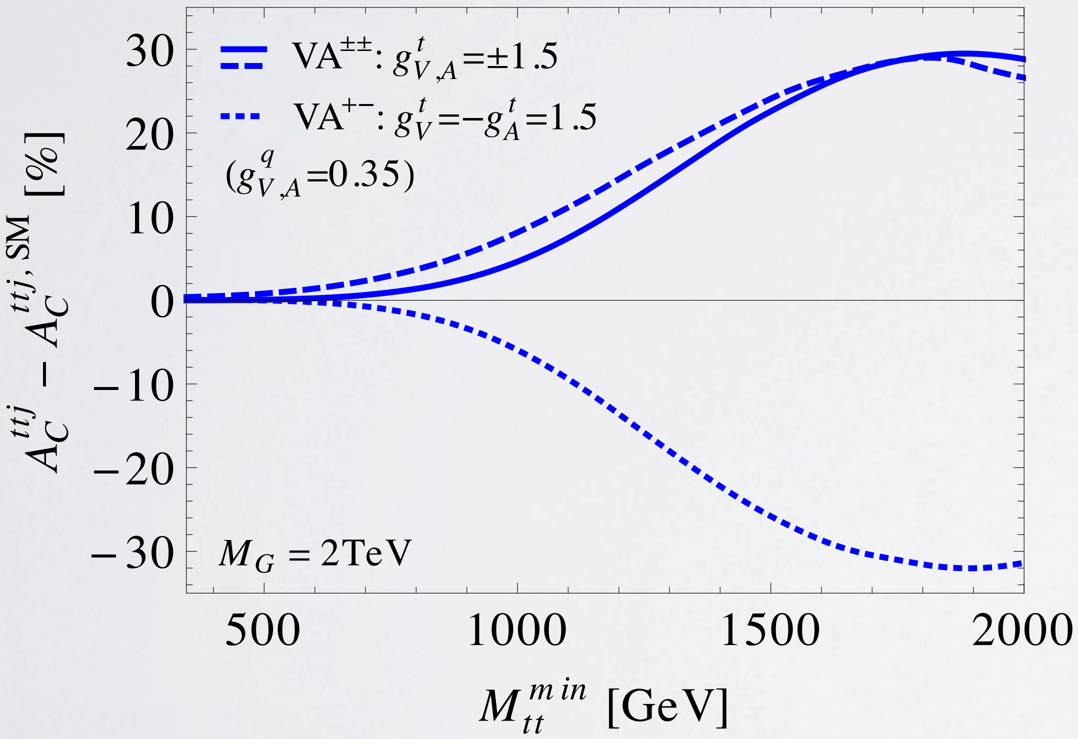
MASSIVE GLUONS IN TOP-PAIR PLUS JET

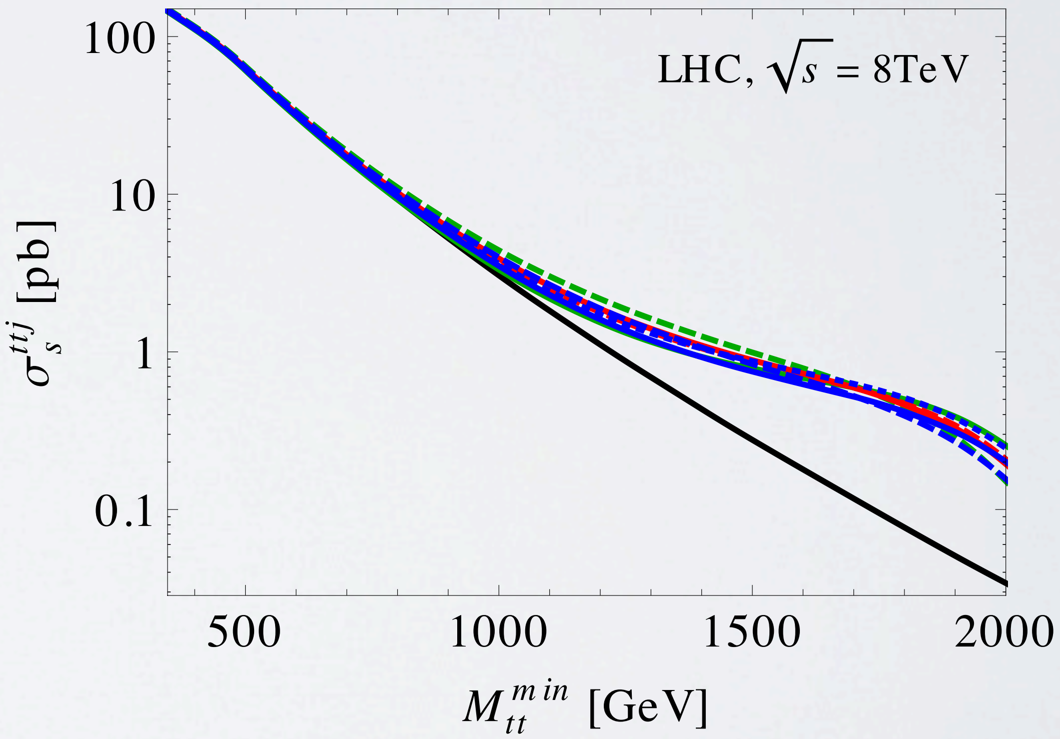
Axial-vector <u>and vector</u> contributions to asymmetry at LO:





A cut on $M_{t\bar{t}}$ enhances the sensitivity to massive resonances.





Additional effects from mixed vector & axial-vector couplings.

[Berge, SW, in preparation][Ferrario, Rodrigo, JHEP 1002 (2010) 051]

TO BE TAKEN HOME

Constraints on massive gluons from LHC7:

- Dijet resonances $\sim (g^q_{V,A})^2$
- Dijet angular distribution $\sim (g^q_{V,A})^2 + \mathcal{O}((g^q_{V,A})^4)$
- $t\bar{t}$ resonances $\sim (g^t_{V,A})^2$ (requires sizeable $g^q_{V,A}$)
- $t\bar{t}$ cross section $\sim g^q_V g^t_V + \mathcal{O}((g^q_{V,A})^2 (g^t_{V,A})^2)$

Axigluon effects on charge asymmetries $\sim -g^q_A g^t_A$:

- Tevatron FB asymmetry $A^t_{\rm FB} \approx 15\%$ (requires strong top cplg.)
- LHC $t\bar{t}$ charge asymmetry $A^y_C \approx 2\%$

LHC $t\bar{t}$+jet charge asymmetry probes $g^q_A g^t_A$ and $g^q_V g^t_V$.