



VNIVERSITAT DE VALÈNCIA



CSIC  
CONSEJO SUPERIOR  
DE INVESTIGACIONES CIENTÍFICAS

# Charge Asymmetries of Top Quarks at LHC

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P. Ferrario, G. Rodrigo, Phys. Rev. D 78, 094018 (2008)

# LHC is starting soon! (hopefully...)

## Runs

- $\sqrt{s} = 14 \text{ TeV}$ ,  $\mathcal{L} = 10 \text{ fb}^{-1}/\text{year}$
- $\sqrt{s} = 14 \text{ TeV}$ ,  $\mathcal{L} = 100 \text{ fb}^{-1}/\text{year}$  in a second phase

## Huge production of top quarks

- More top-antitop quark pairs than in the whole Tevatron life
- $\sqrt{s} = 14 \text{ TeV}$ ,  $\sigma = 950 \text{ pb} \rightarrow$  for  $\mathcal{L} = 10 \text{ fb}^{-1}/\text{year}$  **10 millions of events per year!**
- Possibility of new physics discovery thanks to the high statistics

# Charge asymmetry

Difference in top-antitop production

$$\frac{N_t - N_{\bar{t}}}{N_t + N_{\bar{t}}}$$

- In QCD it is different from zero at  $\mathcal{O}(\alpha^3)$ . [appendix](#)
- Tops are produced mostly in the direction of the quarks.
- It arises mostly from  $q\bar{q}$  and small contribution of  $qg$  events, because  $gg$  is symmetric.

# Resonances

- New physics color-octet resonances have been predicted to be detected at LHC by decaying to top-antitop. Masses under around 1 TeV already ruled out at Tevatron.
- Resonances appear as a **peak in the cross section**  $\rightarrow$  we could observe these resonances in events with invariant masses close to the resonance mass.

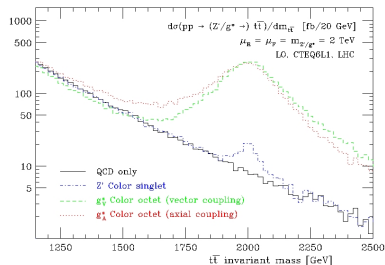


Figure: R. Frederix, F. Maltoni

# Resonances

- High momenta top pairs are difficult to distinguish from light quark jets, because the decay products are more collimated. Standard reconstruction algorithms are not efficient anymore at  $p_T > 400$  GeV. Studies for new algorithms *see*
  - \* Kaplan, Rehermann, Schwartz and Tweedie, arXiv:0806.0848 [hep-ph]
  - \* Thaler and Wang, JHEP 0807 (2008) 092
  - \* L. G. Almeida, S. J. Lee, G. Perez, G. Sterman, I. Sung and J. Virzi, arXiv:0807.0234 [hep-ph]

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- Resonances can produce asymmetries. Since these arise from interference terms, they are more sensitive to higher masses than the differential cross section, because they are less suppressed.
- This makes **more effective studying asymmetries** than cross sections.

# Charge asymmetry @LHC

- At Tevatron charge asymmetry = forward–backward asymmetry  $\simeq 5\%$
- $pp$  is symmetric  $\rightarrow$  no FB asymmetry appendix BUT it's possible to look for a charge asymmetry in an appropriate kinematic region
- Main problem: 85% of the events is  $gg \rightarrow t\bar{t}$  (symmetric)

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Not a problem at LHC

# Pure QCD

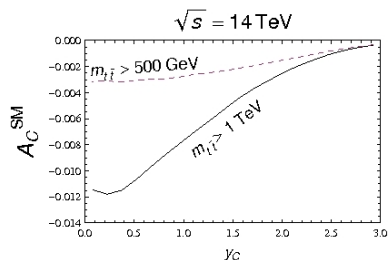
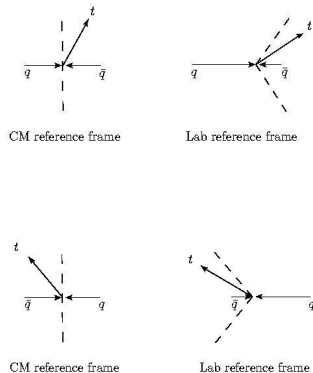
- Central asymmetry, built choosing a limited rapidity region

$$A_C(y_C) = \frac{N_t(|y| \leq y_C) - N_{\bar{t}}(|y| \leq y_C)}{N_t(|y| \leq y_C) + N_{\bar{t}}(|y| \leq y_C)}$$

- Cut on the top-antitop invariant mass  $m_{t\bar{t}}$  to have more  $q\bar{q}$ ,  $gq$  events.

# Pure QCD

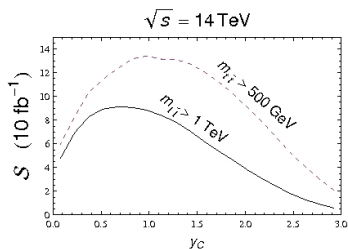
QCD predicts that tops (antitops) are produced mostly in the direction of the incoming quarks (antiquarks)



For low  $y_C$  only the region with more abundant antitops is selected  $\longrightarrow$  the asymmetry is **negative** and decreases in magnitude with  $y_C$

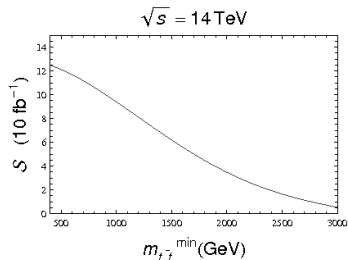
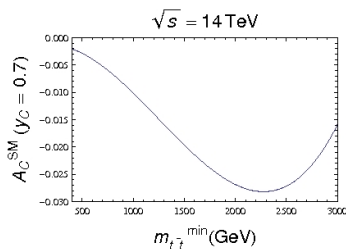
# Pure QCD: significance

$$S^{\text{SM}} = \frac{\text{signal}}{\sqrt{\text{background}}} = \frac{N_t - N_{\bar{t}}}{\sqrt{N_t + N_{\bar{t}}}}$$



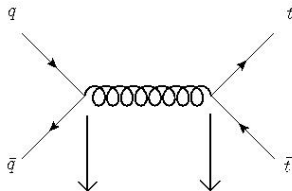
- Significance is greater for lower cuts  $\rightarrow$  identifying soft tops is easier than the highly boosted ones
- The higher statistic compensates the smaller asymmetry
- The maximum is around  $y_C \simeq 0.7 - 1$  and it has a high value

# Pure QCD: asymmetry and significance with fixed $y_C$



- Even if the asymmetry is smaller, the significance is greater at low cuts in  $m_{t\bar{t}}$
- $10 \text{ fb}^{-1}$  luminosity allows charge asymmetry measurement

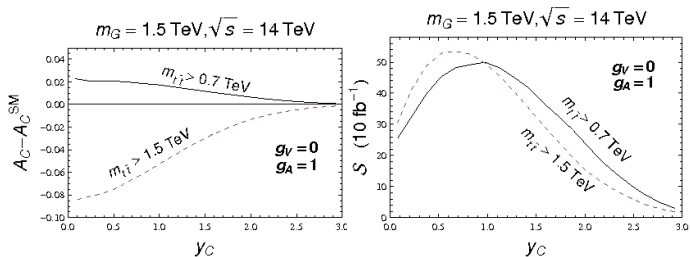
# Color-octet boson resonance exchange



$$(g_V + g_A \gamma_5) \gamma_\mu$$

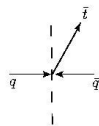
- Arbitrary couplings  $g_V, g_A \in [0, 2]$
- Couplings independent on flavour  $g_{V(A)}^q = g_{V(A)}^t$
- Examples: axigluon ( $g_V = 0, g_A = 1$ ), KK gluon

# Color-octet boson resonances

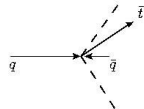


In the partonic cross section cross section we have  $\hat{s} - m_G^2$ , so for low  $\hat{s}$  it is negative  $\rightarrow$

- Positive charge asymmetry for low cuts
- If the cut grows, the asymmetry changes sign and becomes negative
- Maximum for the significance at  $y_C \simeq 0.7$



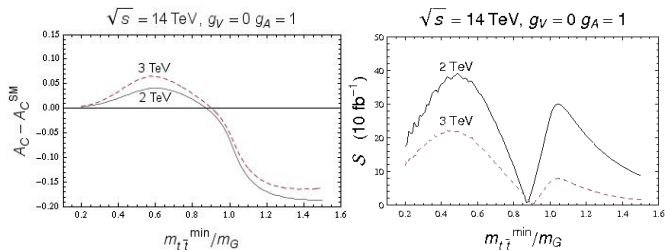
CM reference frame



Lab reference frame

for  $\hat{s} < m_G^2$

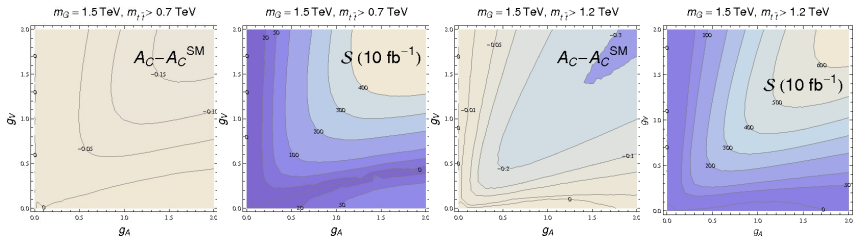
# Varying $m_{t\bar{t}}^{\min}$



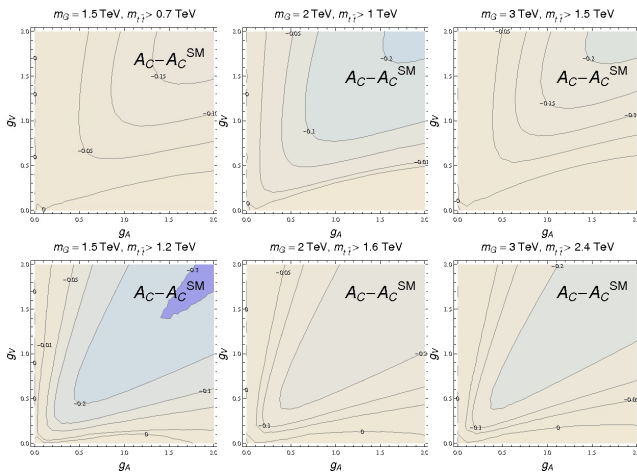
- $A_C$  goes from positive to negative  $\rightarrow S$  reaches a maximum there and goes to zero.
- $A_C$  grows negative  $\rightarrow S$  increases again and has another maximum before the number of events becomes small.
- The maxima are at  $m_{t\bar{t}}^{\min}/m_G = 0.5$  and  $m_{t\bar{t}}^{\min}/m_G = 0.8 - 1$  for almost all couplings  $\rightarrow$  a low cut is enough for a good statistical significance
- The maxima position does not depend on the mass

# Varying the couplings

- Fixed cuts  $m_{t\bar{t}}^{\min}/m_G = 0.5, 0.8$
- Three resonance masses: 1.5 TeV, 2 TeV and 3 TeV



# Varying the couplings



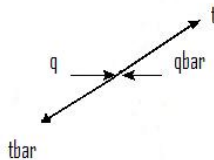
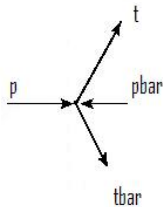
- The pattern depends mainly on  $m_{t\bar{t}}^{\min}/m_G$  and not on  $m_G$
- The asymmetry is sizable for whatever value of  $m_G$

# Conclusions

- Charge asymmetry in top-antitop production in QCD and through a color-octet massive resonance exchange
- @LHC
  - Pure QCD analysis: the statistical significance is greater with no cuts in the invariant mass
  - Resonances: a cut of  $1/2$  the resonance mass is enough to see the asymmetry and detect or exclude these particles

# Appendix

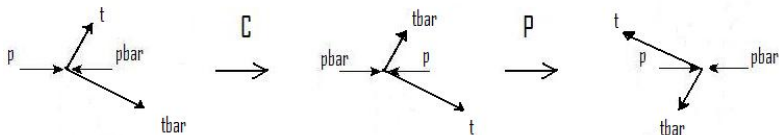
- Pair asymmetry



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# Appendix

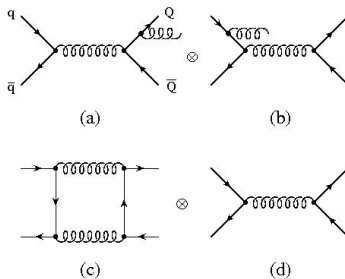
- Tevatron



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# Appendix

- Interference contributions to QCD charge asymmetry



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# Appendix

- Cross section and FB asymmetry

$$\sigma = \int_1^{-1} d \cos \hat{\theta} \frac{d\sigma}{d \cos \hat{\theta}} + \int_{-1}^1 d \cos \hat{\theta} \frac{d\sigma}{d \cos \hat{\theta}}$$

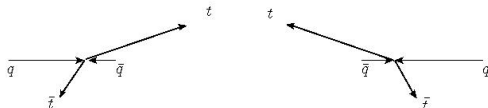
→ only even terms in  $\cos \hat{\theta}$  contribute.

$$A_{\text{FB}} \propto \frac{d\sigma(\cos \hat{\theta})}{d \cos \hat{\theta}} - \frac{d\sigma(-\cos \hat{\theta})}{d \cos \hat{\theta}}$$

→ only odd terms in  $\cos \hat{\theta}$  contribute. [◀ Back](#)

# Appendix

- Charge asymmetry at LHC



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## Color-octet boson resonance: differential cross section

$$\begin{aligned}
\frac{d\sigma^{q\bar{q}\rightarrow t\bar{t}}}{d\cos\hat{\theta}} &= \alpha_s^2 \frac{T_F C_F}{N_C} \frac{\pi\beta}{2\hat{s}} \left( 1 + c^2 + 4m^2 + \frac{2\hat{s}(\hat{s} - m_G^2)}{(\hat{s} - m_G^2)^2 + m_G^2 \Gamma_G^2} [g_V^q g_V^t \times \right. \\
&\times (1 + c^2 + 4m^2) + 2g_A^q g_A^t c] + \frac{\hat{s}^2}{(\hat{s} - m_G^2)^2 + m_G^2 \Gamma_G^2} \times \\
&\times \left[ ((g_V^q)^2 + (g_A^q)^2) ((g_V^t)^2 (1 + c^2 + 4m^2) + \right. \\
&\left. \left. + (g_A^t)^2 (1 + c^2 - 4m^2)) + 8g_V^q g_A^q g_V^t g_A^t c \right] \right) \\
c &\equiv \sqrt{1 - 4 \frac{m_t^2}{\hat{s}}} \cos\hat{\theta} \quad \text{appendix}
\end{aligned}$$

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