Charge Asymmetries of Top Quarks: a Window to New Physics at Hadron Colliders

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

LHC is starting soon! (hopefully...)

Runs

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

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Huge production of top quarks

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

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** → we could observe these resonances in events with invariant masses close to the resonance mass.

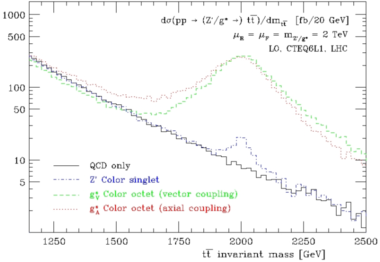

Figure: R. Frederix, F. Maltoni

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 BUT it's possible to look for a charge asymmetry in an appropriate kinematic region appendix
- Main problem: 85% of the events is $gg \rightarrow t\bar{t}$ (symmetric)

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Not a problem at LHC

Pure QCD

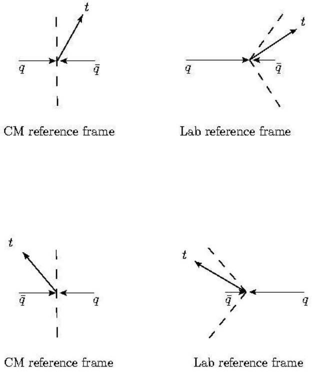
- Central asymmetry, built choosing a limited rapidity region

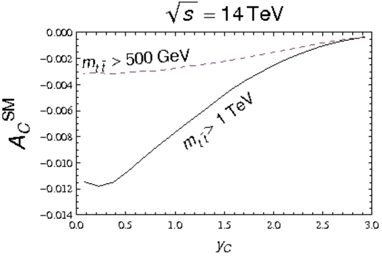
$$A_C(y_C) = \frac{N_t(|y| \leq y_C) - N_{\bar{t}}(|y| \leq y_C)}{N_t(|y| \leq y_C) + N_{\bar{t}}(|y| \leq y_C)}$$

- 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)

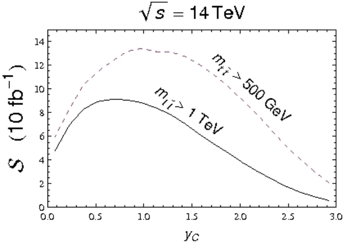




For low y_C only the region with more abundant antitops is selected $\longrightarrow$ the asymmetry is negative and decreases in magnitude with y_C

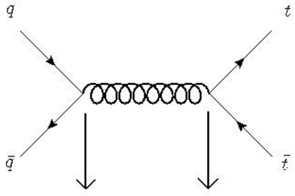
Pure QCD: significance

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



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

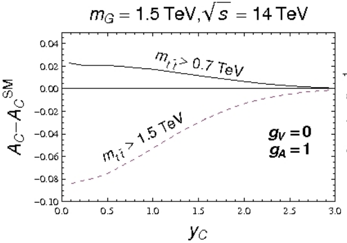
Color-octet boson resonance exchange

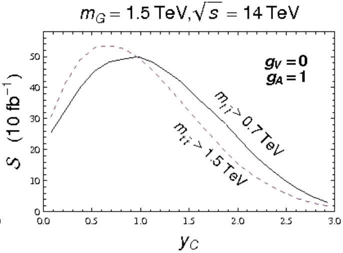


$$\Big(g_V + g_A\gamma_5\Big)\gamma_\mu$$

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

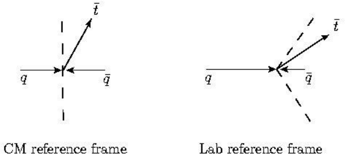
Color-octet boson resonances





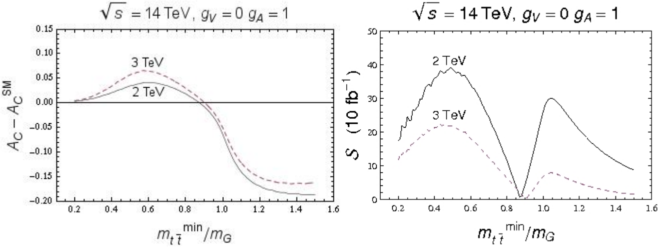
In the partonic cross section cross section we have $\hat{s} - m_G^2$, so for low $\hat{s}$ it is negative $\longrightarrow$

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



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

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



- A_C goes from positive to negative $\rightarrow \mathcal{S}$ reaches a maximum there and goes to zero.
- A_C grows negative $\rightarrow \mathcal{S}$ 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

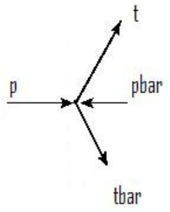
Conclusions

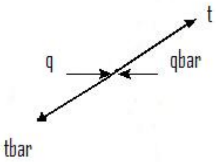
- Charge asymmetry in top-antitop production in QCD and through a color-octet massive resonance exchange
- @LHC
  - Pure QCD analysis: the statistical significance is greater with no cuts in the invariant mass
  - Resonances: a cut of 1/2 the resonance mass is enough to see the asymmetry and detect or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

¡Gracias!

Appendix

- Pair asymmetry





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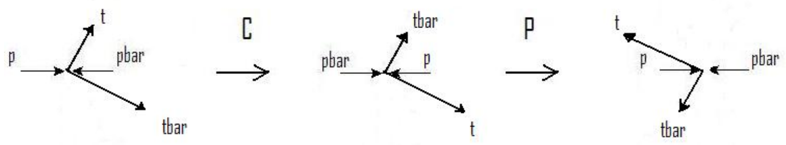
Appendix

- Tevatron



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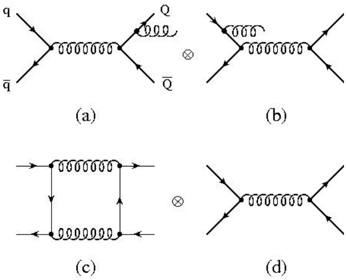
Appendix

- Interference contributions to QCD charge asymmetry



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Appendix

- Cross section and FB asymmetry

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

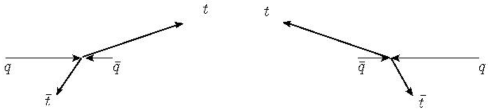
$\longrightarrow$ only even terms in $\cos\hat{\theta}$ contribute.

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

$\longrightarrow$ 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

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

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