



VNIVERSITAT ID VALÈNCIA



CSIC CONSEJO SUPERIOR  
DE INVESTIGACIONES CIENTÍFICAS

# Charge asymmetry of top quarks

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DIS 2010, Firenze, April 20

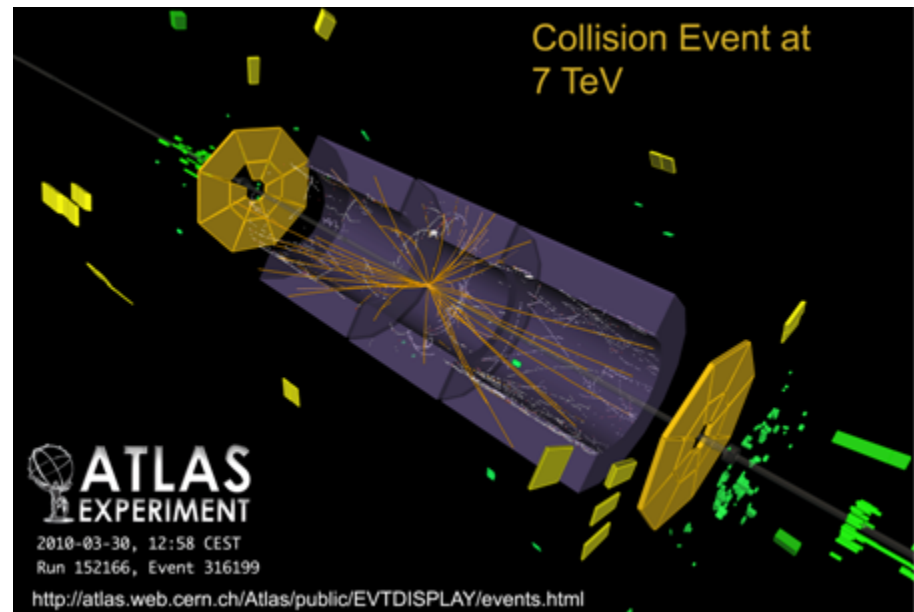
# The LHC has started running!

- 30/3/2010: first collisions at 7 TeV c. m.
- 18 to 24 months at 7 TeV, planned integrated luminosity  $1 \text{ fb}^{-1}$

The LHC is a top machine:  
950 pb at 14 TeV for top-antitop

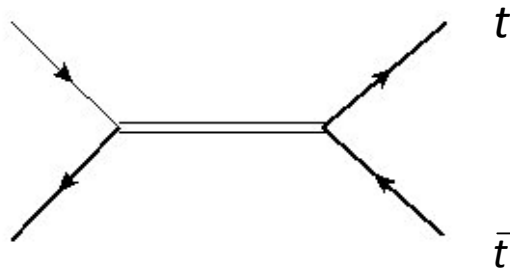


$10^5$  top-antitop pairs  
in the first running



# Testing new physics in top production

Colored resonances decaying to top-antitop pairs could leave a sign



$$\mathcal{L}_{\text{res.}} \equiv ig_s \bar{\psi}_q \gamma^\mu (g_V^q + g_A^q \gamma_5) R_\mu^a T_a \psi_q$$

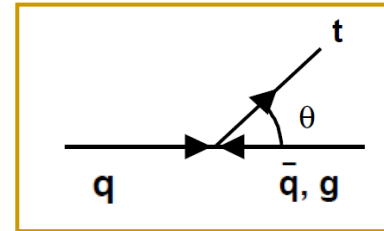
- Chiral color models and axigluons (purely axial-vector coupling ) [Pati , Salam, PLB58(1975)333; Hall,Nelson, PLB153(1985)430; Frampton, Glashow, PLB190(1987)157; PRL58(1987)2168]
- Colorons (purely vector coupling ) [Hill, PLB266(1991)419; Hill, Parke, PRD 49(1994)4454; Chivukula, Cohen, Simmons, PLB380(1996)92]
- Top color models [Hill, PLB345(1995)483; Lane, Ramana, PRD 44 (1991) 2678; Lane, Mrenna, PRD67(2003) 115011]
- Kaluza-Klein excitations in extra dimensional RS models [Randall, Sundrum, PRL 83, 3370 (1999); Dicus, McMullen, Nandi, PRD65 (2002) 076007]

Typical signature: peak in the differential cross section

Other possibility: a sizable **charge asymmetry**

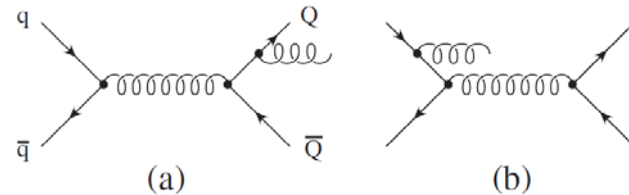
# The charge asymmetry in QCD

$$A(\cos \theta) = \frac{N_t(\cos \theta) - N_{\bar{t}}(\cos \theta)}{N_t(\cos \theta) + N_{\bar{t}}(\cos \theta)}$$

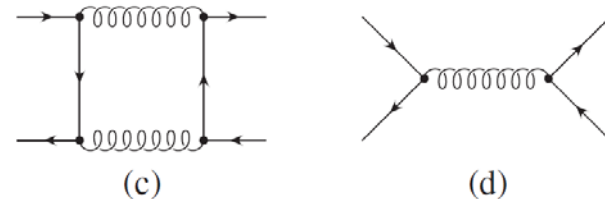


It arises from  $\mathcal{O}(\alpha_s^3)$  contributions

negative contribution



positive contribution,  
larger than the other



- Contribution from  $qg \rightarrow t\bar{t}q$  very small
- Gluon gluon fusion is charge symmetric

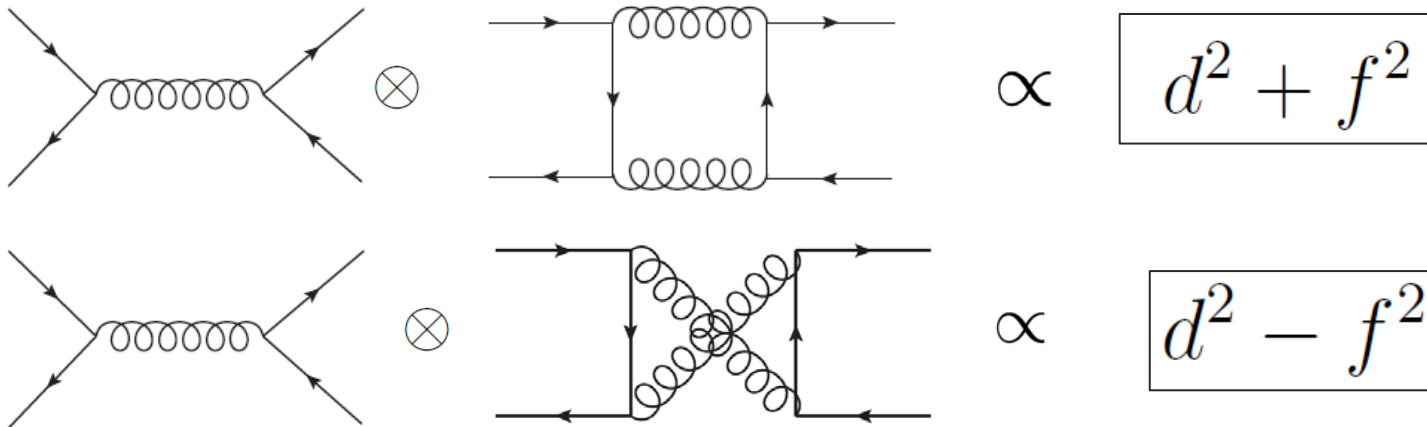
FIG. 1. Origin of the QCD charge asymmetry in hadro production of heavy quarks: interference of final-state (a) with initial-state (b) gluon bremsstrahlung, plus interference of the double virtual gluon exchange (c) with the Born diagram (d).

J. H. Kühn, G. Rodrigo, (1998)

# Where does it come from?

- QED: the products of these diagrams are odd under C-conjugation
- QCD: C-even and C-odd components.

Color factors:



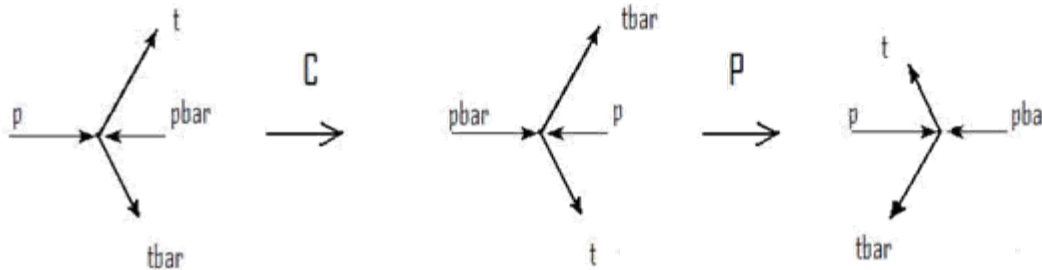
$$d^2 = d_{abc}d^{abc}, \quad f^2 = f_{abc}f^{abc}$$

Asymmetry selects  $d^2$  factor, color singlet quark-antiquark

# The charge asymmetry at the Tevatron

Charge asymmetry = FB asymmetry, from CP conservation

see talks by F. Garberson and H. Schellman



$$A_{\text{FB}}^{p\bar{p}} = 0.193 \pm 0.065_{\text{stat.}} \pm 0.024_{\text{syst.}} (3.2\text{fb}^{-1})$$

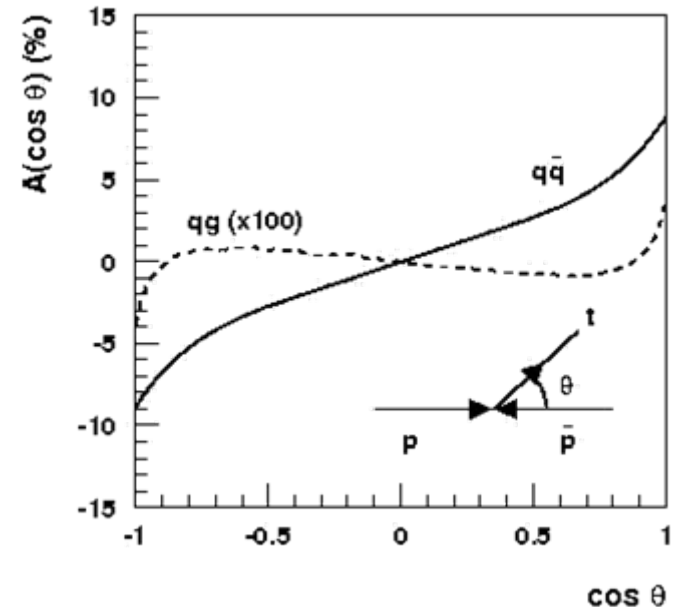
$$A_{\text{FB}}^{p\bar{p}} = 0.17 \pm 0.07_{\text{stat.}} \pm 0.04_{\text{syst.}} (1.9\text{fb}^{-1})$$

Theoretical prediction:

$$A = 0.051(6)$$

J. H. Kühn, G. Rodrigo, 1998

2 sigma discrepancy:  
new physics with positive contribution?



# Scalars, $Z'$ and $W'$ in t/u/s-channel

## t-channel

- Flavour violating scalars [Shu, Tait, Wang, Phys.Rev.D81:034012, 2010. ]
- RPV-MSSM,  $Z'$  in the LR model [Cao, Heng, Wu, Yang, Phys.Rev.D81:014016, 2010]
- $W'$  coupling with d and t quarks [Cheung, Keung, Yuan, Phys.Lett.B682:287-290, 2009]

## u-channel

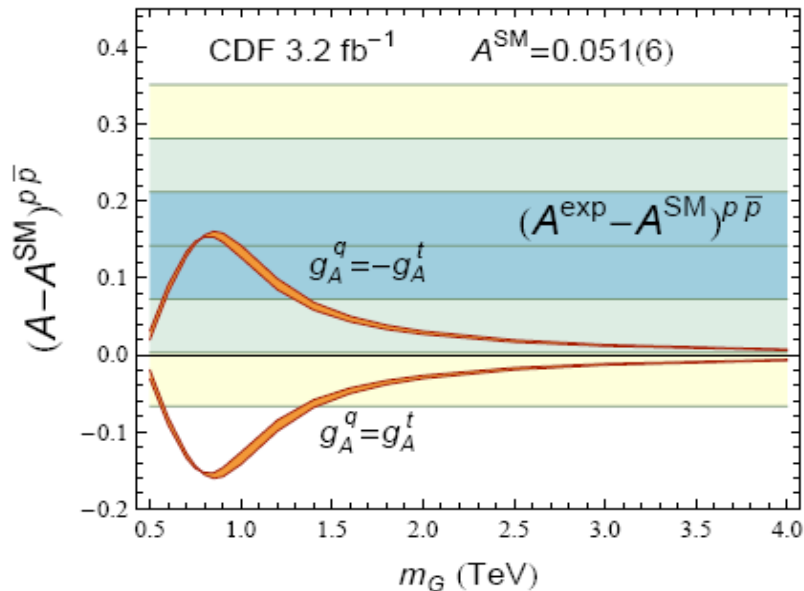
- Scalars in di-quark models [Arhrib, Benbrik, Chen, arXiv:0911.4875]
- Light colored scalars in SU(5) GUT model [Dorsner et.al. arXiv:0912.0972]
- Model independent approach, Effective Lagrangian [Jung, Ko, Lee, Nam, arXiv:0912.1105]
- Asymmetric LR model  $SU(2)_L \times SU(2)' \times U(1)' \rightarrow U(1)_Y$  [Barger, Keung, Yu, arXiv:1002.1040]
- $Z'$  with flavour-changing couplings to u and t quarks [Jung, Murayama, Pierce, Wells, Phys.Rev.D81:015004, 2010 ]

In general large flavour violating couplings are required

# Can resonances generate an asymmetry?

Chiral color models:  $SU(3)_L \times SU(3)_R \rightarrow SU(3)_C$

- New color-octet massive gauge boson: the axigluon
- Only axial-vector coupling with the quarks, same strength as QCD
- At the Tevatron, a negative asymmetry is disfavoured at two sigmas



What about flavor non-universal couplings?

Axial-vector coupling with opposite sign between light and top quarks

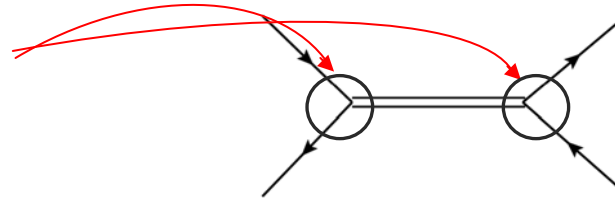
PF, G. Rodrigo, 2009



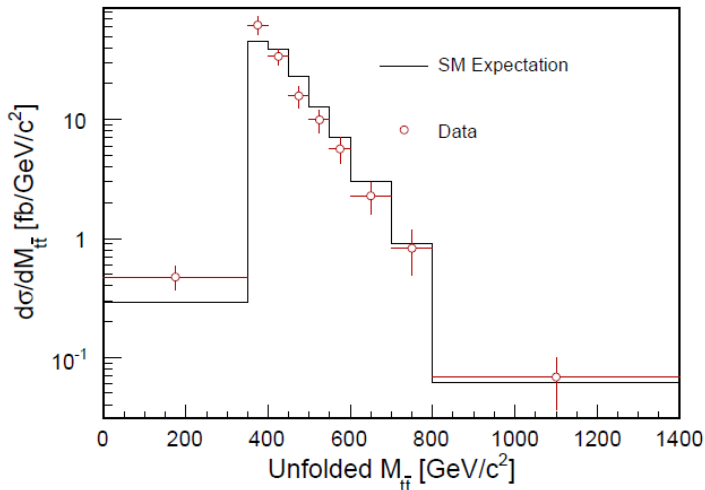
# Model independent heavy color-octet resonance

Flavor-dependent vector and axial-vector coupling with the quarks

$$g_s (g_V^q \gamma^\mu + g_A^q \gamma^\mu \gamma_5)$$



Two constraints: asymmetry and differential invariant  $t\bar{t}$  mass distribution



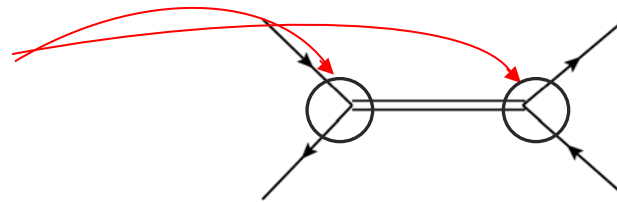
CDF Collaboration, (2009)

Last bins can be affected by a resonance even if the total cross section does not change significantly

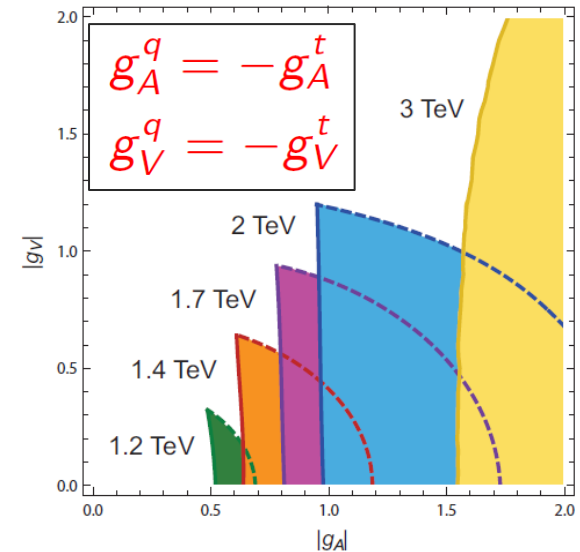
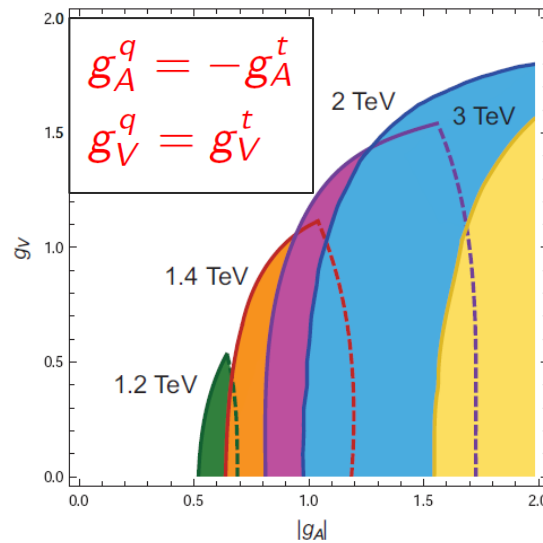
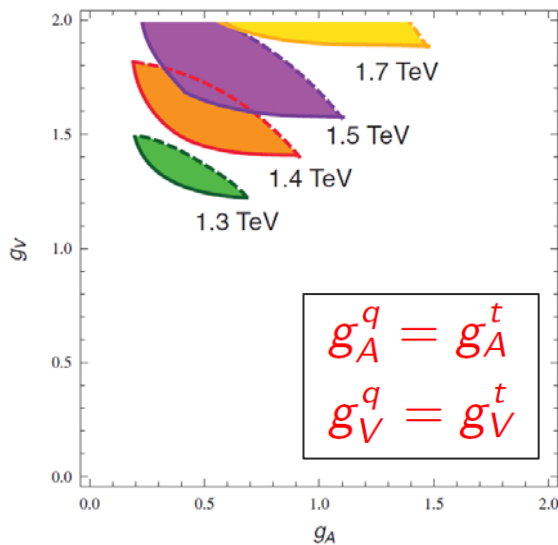
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Asymmetry  $\rightarrow$  lower bound on the couplings, invariant mass distribution  $\rightarrow$  upper bound

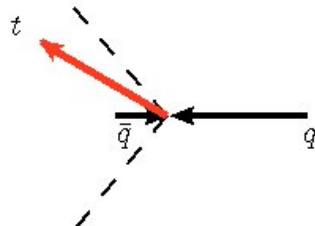
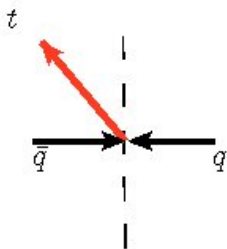
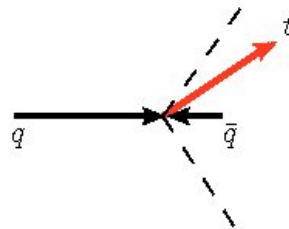
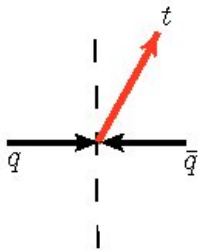


PF, G. Rodrigo, 2009

# The charge asymmetry at the LHC

pp is **symmetric** → FB asymmetry **vanishes**

But a charge asymmetry **exists** in selected kinematic regions



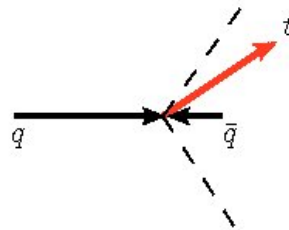
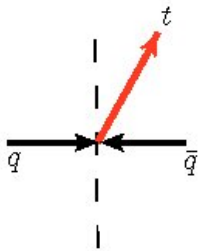
CM: preferred direction

Lab: preferred direction

# The charge asymmetry at the LHC

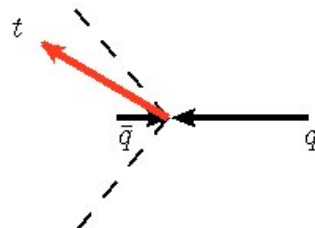
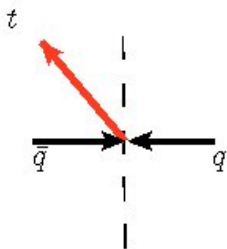
pp is **symmetric** → FB asymmetry **vanishes**

But a charge asymmetry **exists** in selected kinematic regions



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

- depends on a maximum rapidity
- if  $y_C \gg 1$ , it vanishes
- it has opposite sign to the partonic asymmetry



CM: preferred direction

Lab: preferred direction

# The charge asymmetry at the LHC

**Main problem:** 85 % events is gg, i. e. **symmetric!**

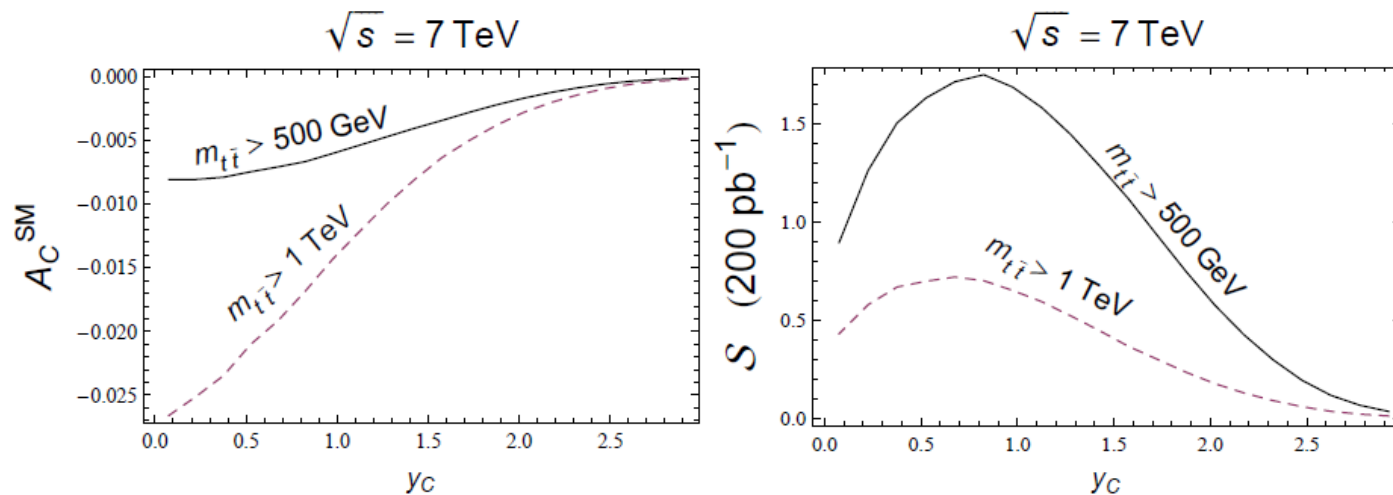
**Solution:** at low x the gluon contribution dominates → **cuts** on the **top-antitop invariant mass** eliminate low x momenta where gluon density is bigger than the quark one



Lower statistic, but not a problem at the LHC!

# The charge asymmetry at the LHC

QCD

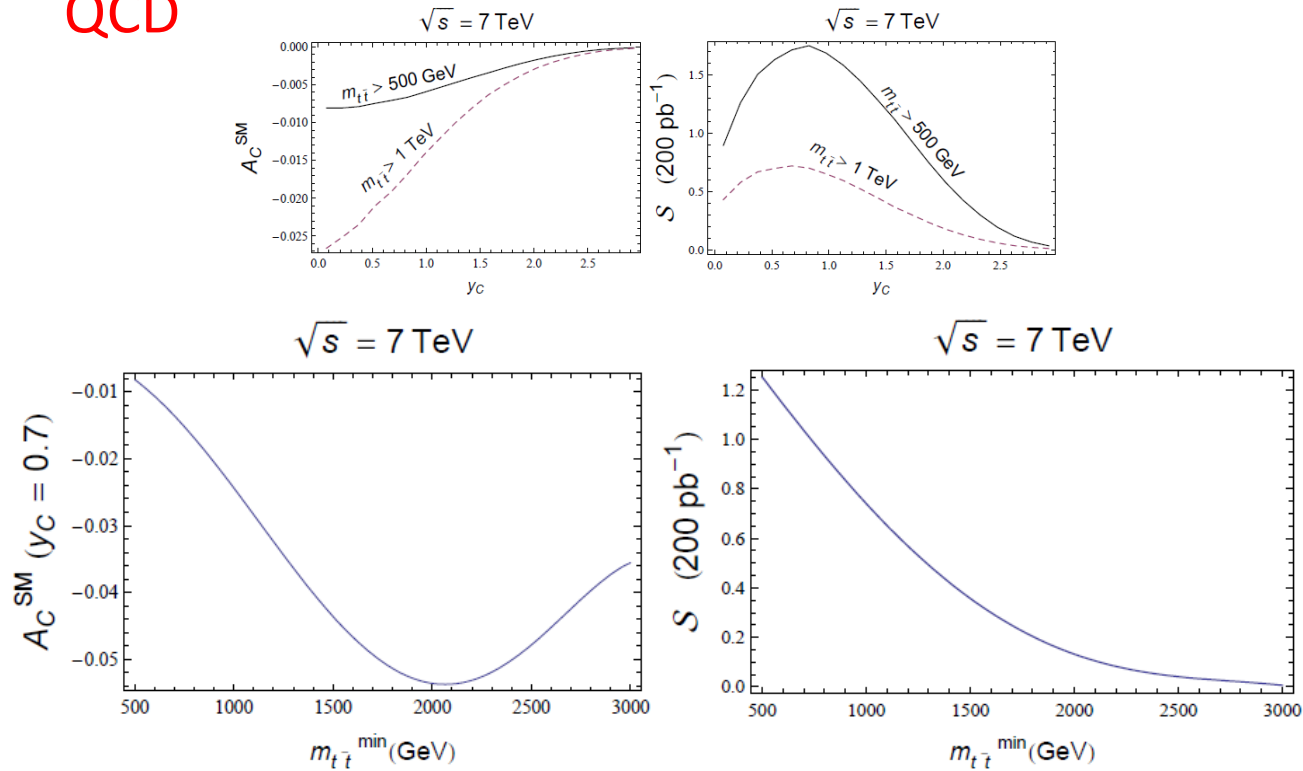


PF, G. Rodrigo, 2008

- The cut enhances the asymmetry
- The statistical significance is higher for lower cuts: the statistic compensates!

# The charge asymmetry at the LHC

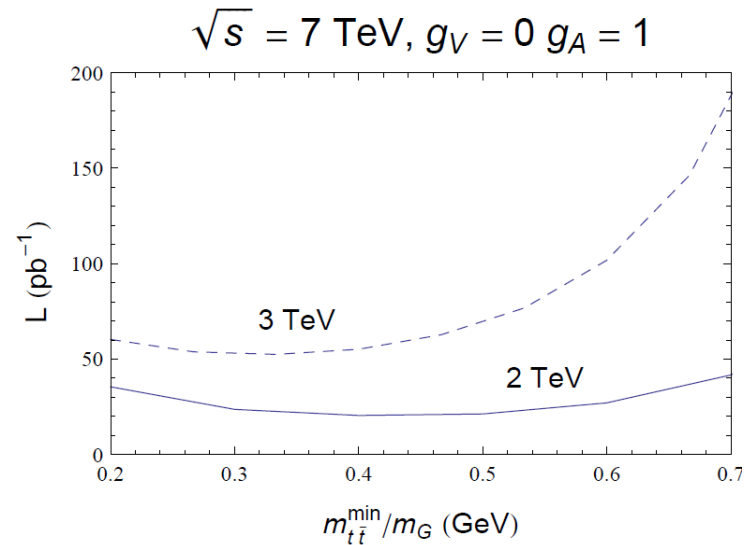
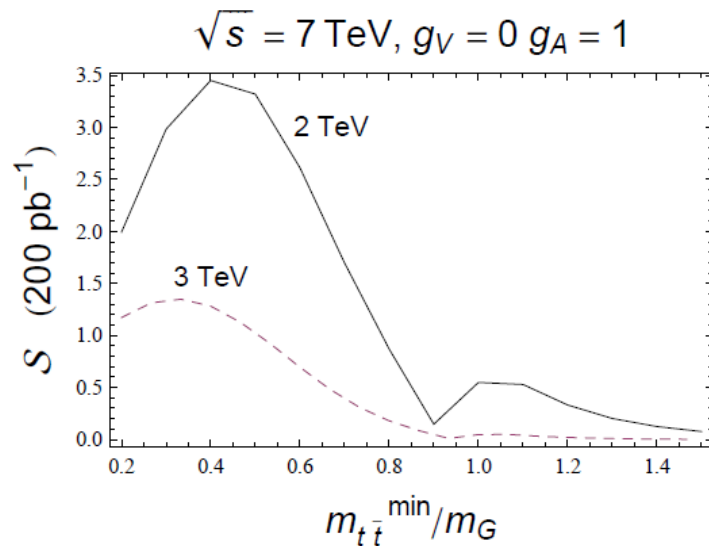
QCD



The statistical significance is higher for lower cuts: **less boosted tops!**

# The charge asymmetry at the LHC

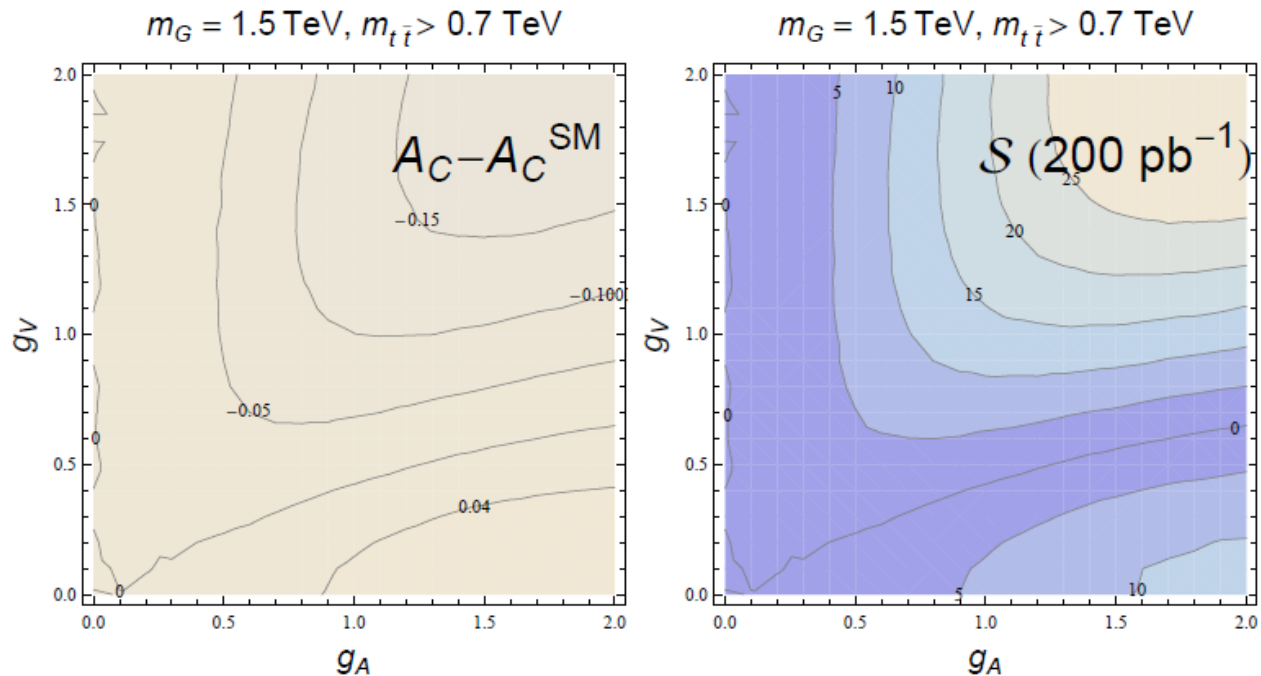
## HEAVY RESONANCES



- ❑ The maximum is also at low cuts  $\sim m_G/2$
- ❑ The luminosity to have  $S = 5$  has a correspondent minimum



# The charge asymmetry at the LHC



- ❑ The pattern depends mainly on  $m_{t\bar{t}}^{\text{min.}} / m_G$  not just the mass
- ❑ Sizable asymmetry for every value of the mass

# The charge asymmetry at the LHC: t-tbar + jet

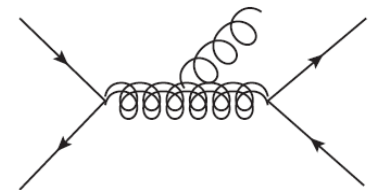
Some models don't produce asymmetry in the inclusive process



Look in ttbar + jet!

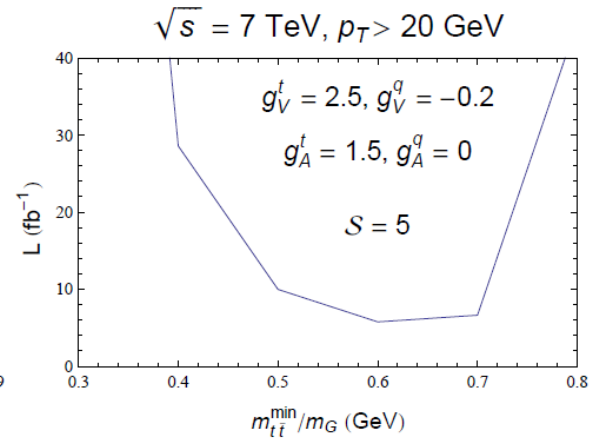
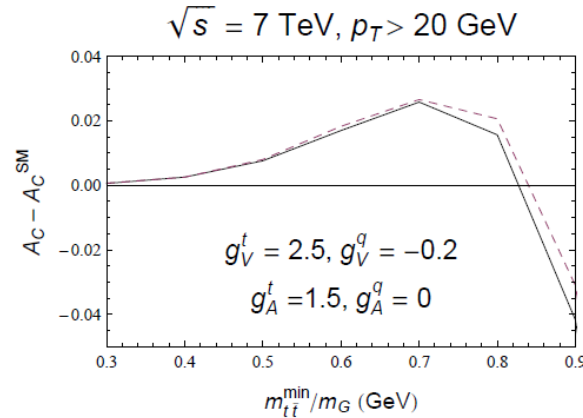
Ex. Kaluza Klein excitations of SM gluons, no axial-vector coupling with light quarks

- LO effect
- One more graph to contribute
- Contributions from both color-octet and color-singlet states



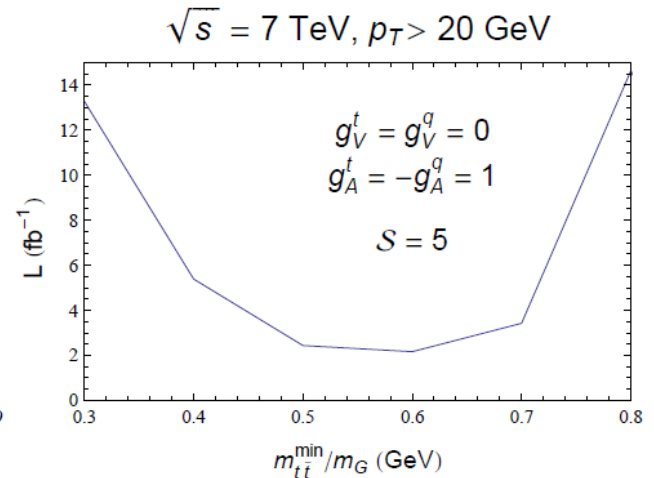
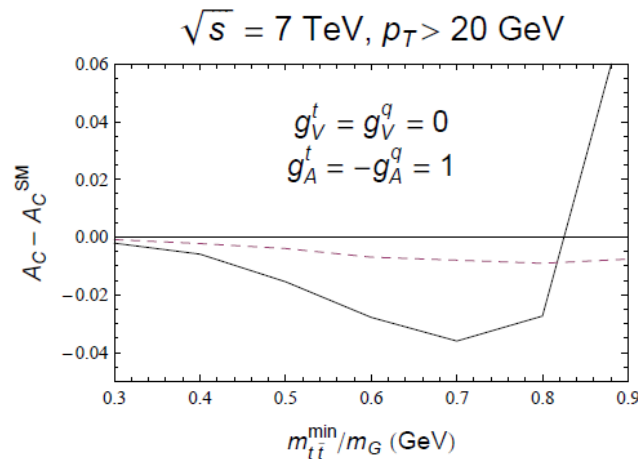
# The charge asymmetry at the LHC: t-tbar + jet

Kaluza Klein  
gluon excitation



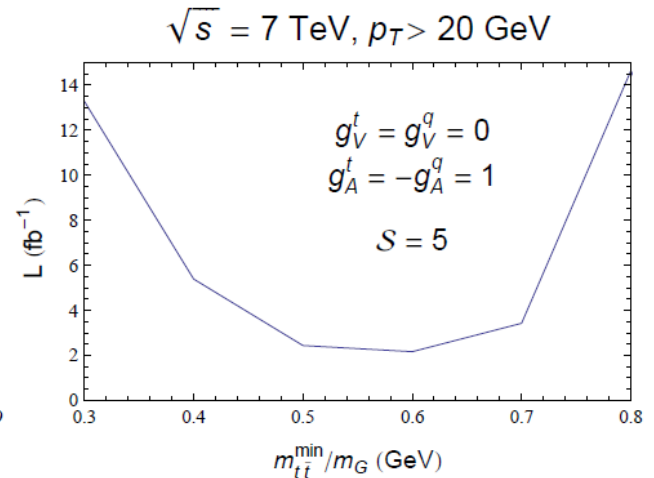
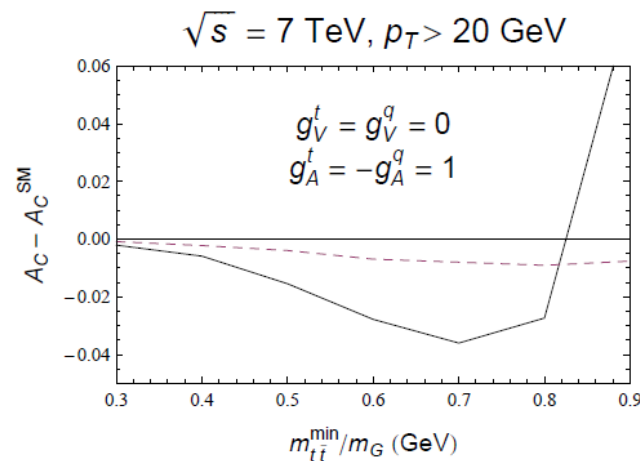
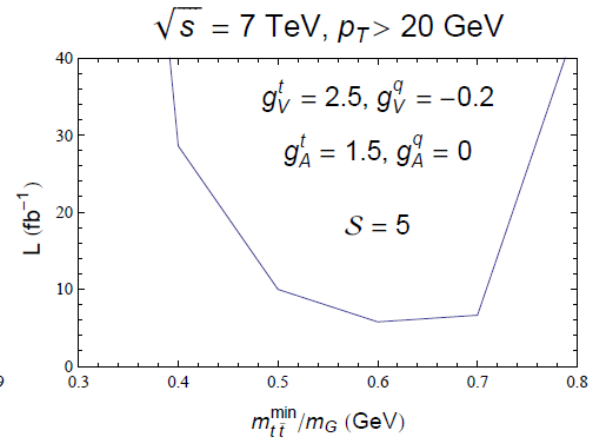
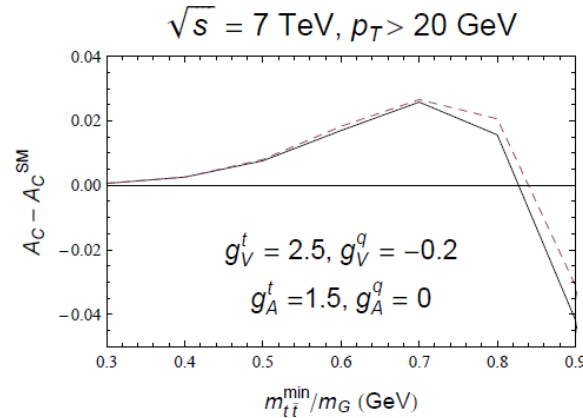
$m_G = 1.5 \text{ TeV}$

“Modified” axigluon



# The charge asymmetry at the LHC: t-tbar + jet

Minimum for low cuts



# Conclusions

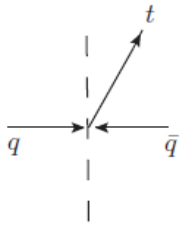
- Room for improvement in statistic at the Tevatron → better constraint from AFB.
- Flavor universal couplings strictly constrained, larger parameter space for  $g_A^q = -g_A^t$
- Central asymmetry at the LHC in a selected kinematic region:  
both inclusive and  $t\bar{t} + \text{jet}$  processes have maximum significance for relatively small cuts on the invariant mass.
- Promising measurement, although challenging: waiting for a huge statistic!

# Conclusions

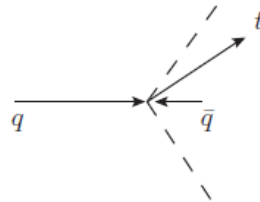
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**Grazie!**

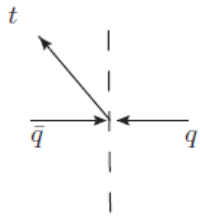
# [ Figure di backup ]



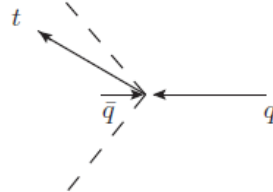
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