CHARGE ASYMMETRY in TOP PRODUCTION:

STANDARD MODEL PREDICTIONS

J. H. Kühn

J.K., G. Rodrigo: PRL 81, 49 (1998)
J.K., G. Rodrigo: PRD 59, 054017 (1999)
O. Antuñano, J.K., G. Rodrigo: PRD 77, 014003 (2008)
J.K., G. Rodrigo: JHEP 1201, (2012) 063

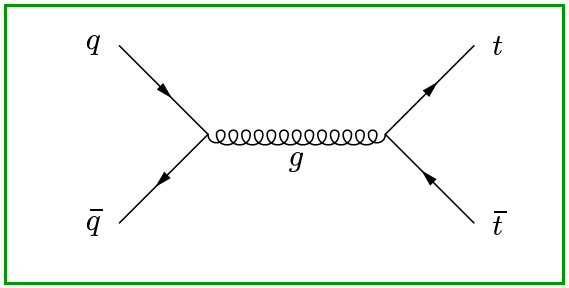
I. Motivation and Main Idea

II. Results at Partonic Level

III. Asymmetries at Tevatron and LHC

I MOTIVATION and MAIN IDEA

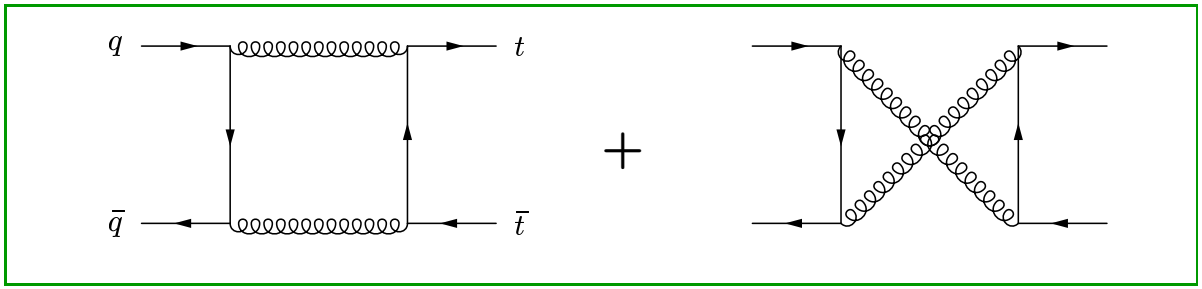
dominant process for $t\bar{t}$ production at Tevatron



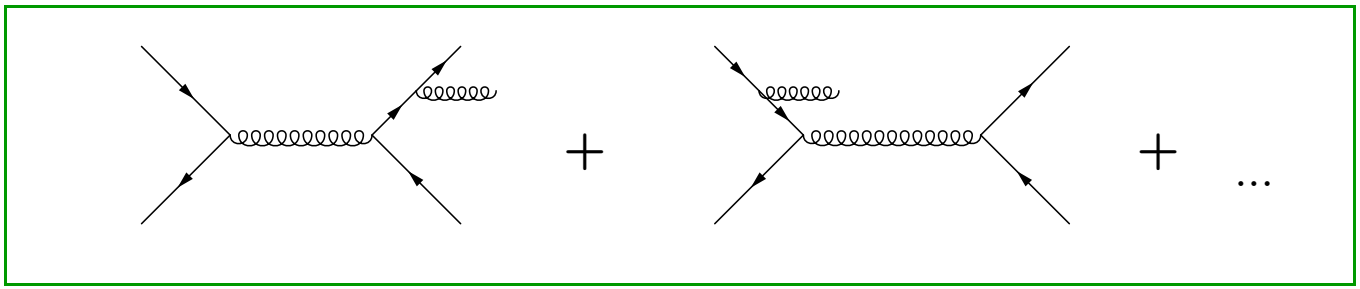
. . . is symmetric:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\hat{\Theta}} \propto \left(1+\frac{4m^2}{Q^2}\right) + \left(1-\frac{4m^2}{Q^2}\right)\cos^2\hat{\Theta}$$

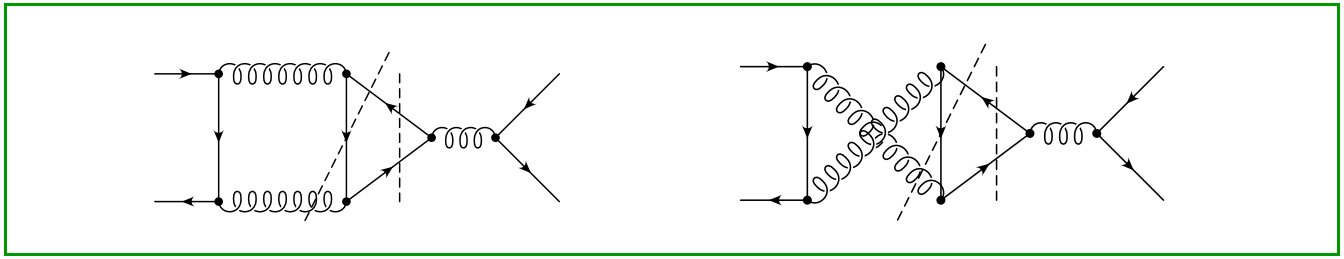
$\mathcal{O}(\alpha_s)$ corrections: virtual gluons



real emission



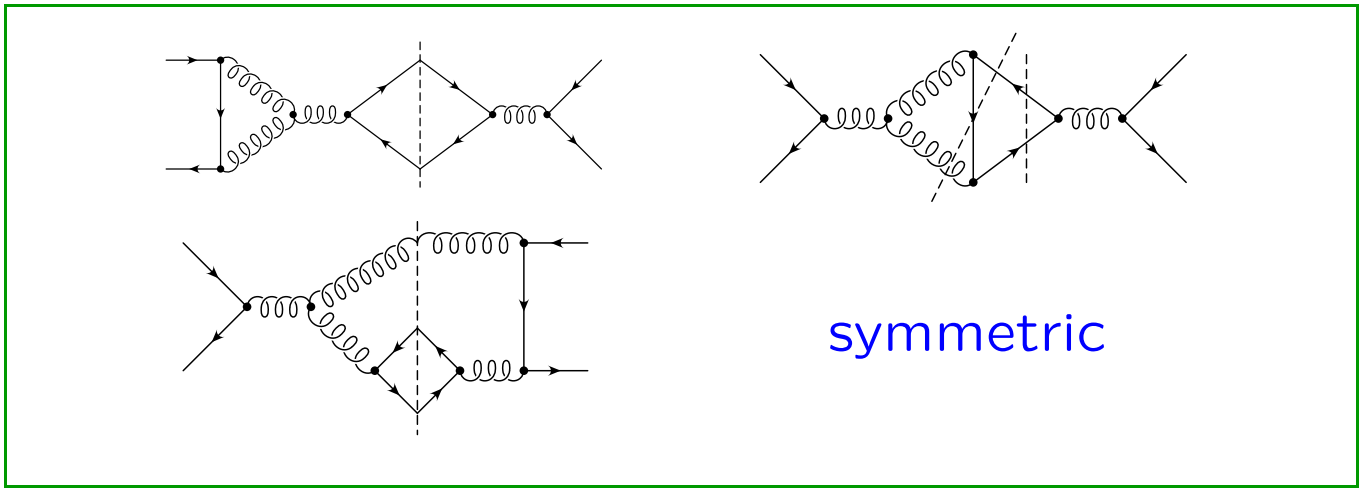
Interference between $C = +1$ and $C = -1$ amplitudes



$\Rightarrow$ charge asymmetry
similar to QED!

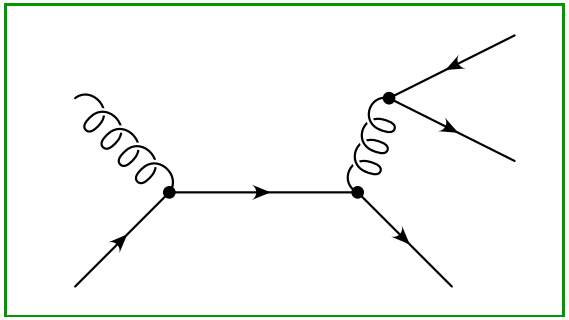
$$\mathrm{d}\sigma(q\bar{q} \to QX) - \mathrm{d}\sigma(q\bar{q} \to \bar{Q}X) \neq 0$$

Nonabelian terms:



similarly ("flavour excitation")
numerically unimportant

$$\mathrm{d}\sigma(qg \to QX) - \mathrm{d}\sigma(qg \to \bar{Q}X) \neq 0$$



real and virtual corrections must be combined to obtain sensible (=IR–finite) result

$\Rightarrow$ forward–backward asymmetry of top quarks in $p\bar{p}$ collisions (TEVATRON)

$\Rightarrow$ difference in rapidity distributions between t and $\bar{t}$ in pp collisions (LHC)

$\Rightarrow$ test of production mechanism

Intuitive picture

inclusive cross section

top and light quark in same direction

preferred coherence with gluon field!

$\Rightarrow$ positive asymmetry for

inclusive cross section

$t\bar{t}g$

propability for gluon emission enhanced

if t and q in opposite direction

$\Rightarrow$ negative asymmetry for $t\bar{t}g$

(tagged events)

semi inclusive cross section

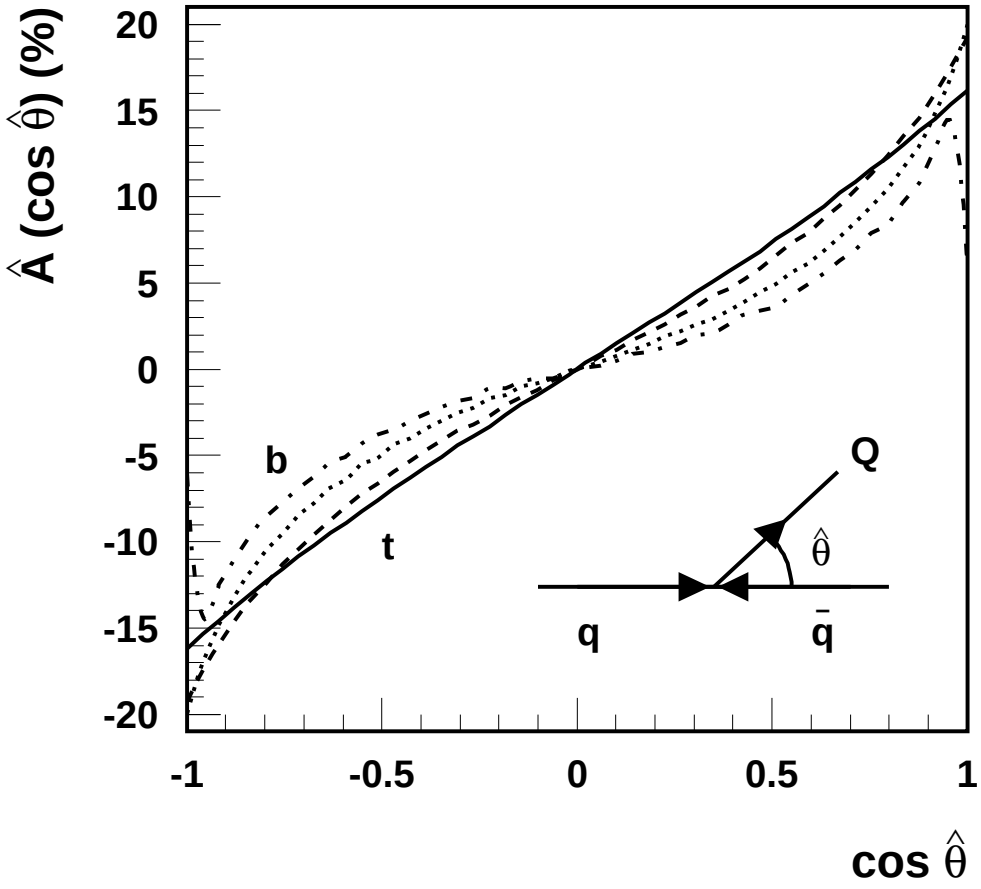
cuts on gluon emission ($\widehat{=} p_T$ of $t\bar{t}$)!

$\Rightarrow$ enhancement of asymmetry

II PARTONIC LEVEL

differential asymmetry
($q\bar{q}$ induced)

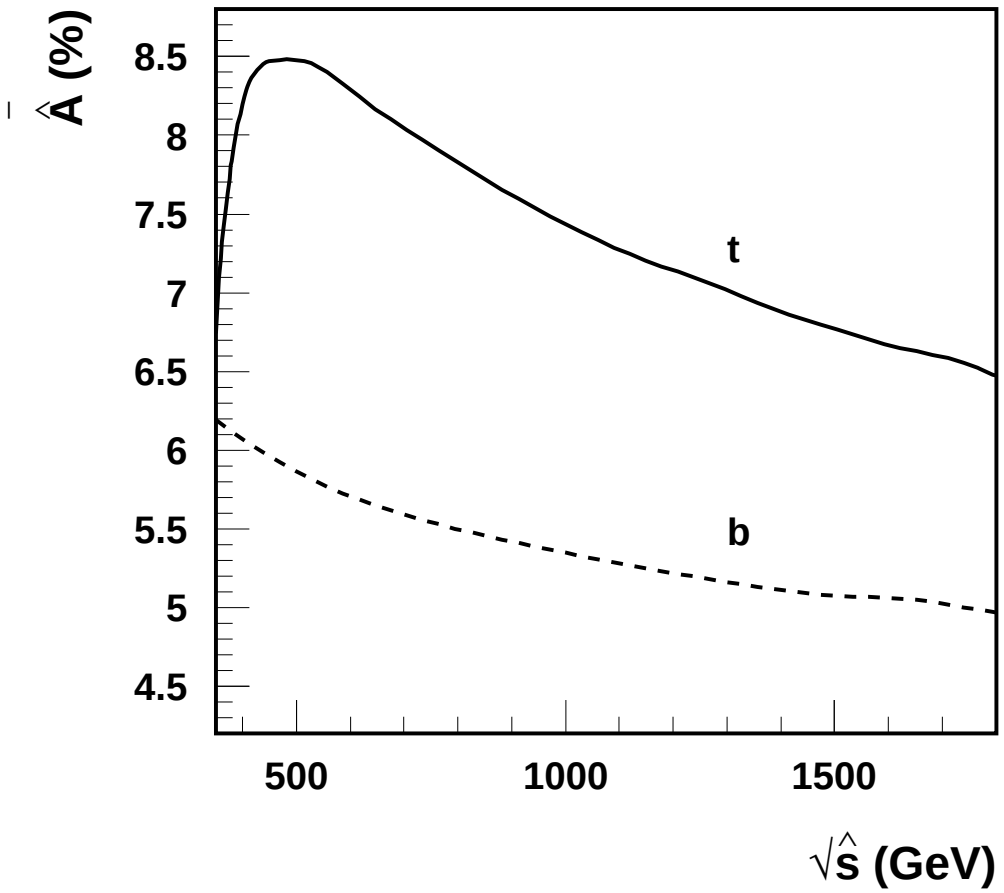
$$\hat{A}(\cos\hat{\Theta}) = \frac{N_t(\cos\hat{\Theta}) - N_{\bar{t}}(\cos\hat{\Theta})}{N_t(\cos\hat{\Theta}) + N_{\bar{t}}(\cos\hat{\Theta})} = \frac{N_t(\cos\hat{\Theta}) - N_{\bar{t}}(-\cos\hat{\Theta})}{N_t(\cos\hat{\Theta}) + N_{\bar{t}}(-\cos\hat{\Theta})}$$



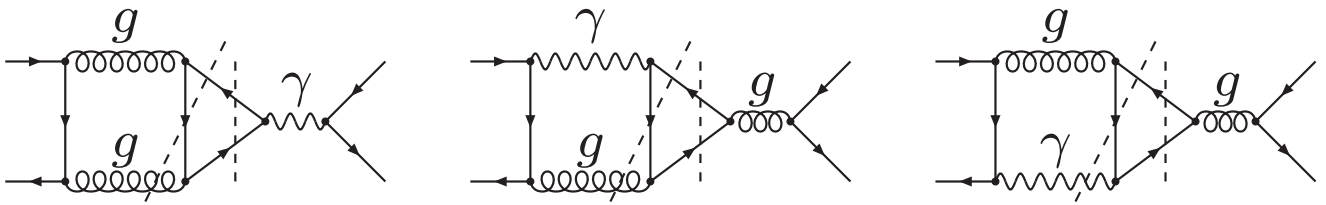
integrated asymmetry
(parton level)

$$\hat{A}(\cos\hat{\Theta}) = \frac{N_t(\cos\hat{\Theta} \geq 0) - N_{\bar{t}}(\cos\hat{\Theta} \geq 0)}{N_t(\cos\hat{\Theta} \geq 0) + N_{\bar{t}}(\cos\hat{\Theta} \geq 0)} = \frac{N_t(\cos\hat{\Theta} \geq 0) - N_t(\cos\hat{\Theta} \leq 0)}{N_t(\cos\hat{\Theta} \geq 0) + N_t(\cos\hat{\Theta} \leq 0)}$$

as function of $\sqrt{\hat{s}}$:



EW corrections (QED)



(a) (b) (c)

Relative factor between QCD and QED

$$f_q^{\mathrm{QED}} = 3\,\frac{\alpha_{\mathrm{QED}}\,Q_t\,Q_q}{\frac{\alpha_S}{2}\left(\frac{d^2_{abc}}{4}\right)^2} = \frac{\alpha_{\mathrm{QED}}}{\alpha_S}\,\frac{36}{5}\,Q_t\,Q_q$$

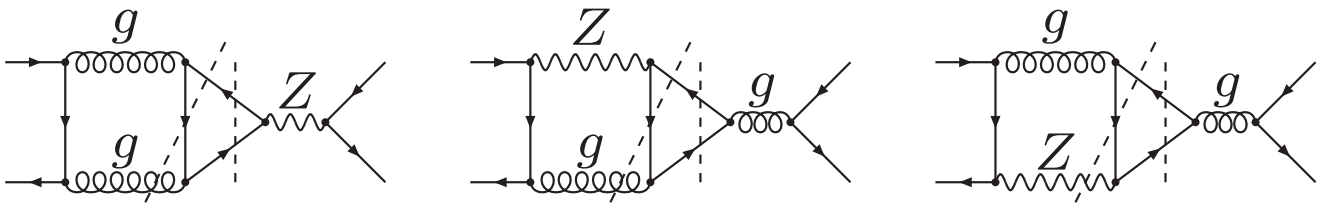
Assuming the ratio 4 : 1 (2 : 1 @LHC) for $u\bar{u}$: $d\bar{d}$ events

$$f^{\mathrm{QED}} = \frac{4f_u^{\mathrm{QED}} + f_d^{\mathrm{QED}}}{5} \approx 0.18$$

$$f^{\mathrm{QED}} = \frac{2f_u^{\mathrm{QED}} + f_d^{\mathrm{QED}}}{3} \approx 0.13$$

PDFs modify these ratios slightly, but do not change the predictions significantly.

EW corrections (weak)



$$f^{\text{weak}} = 3\frac{\alpha_{\text{QED}}}{\alpha_S}\,\frac{36}{5}\,\frac{1-\frac{8}{3}\,s_W^2}{1-m_Z^2/\hat{s}}\,\frac{1}{16\,s_W^2\,c_W^2}\,\frac{4(1-\frac{8}{3}\,s_W^2)+(-1+\frac{4}{3}\,s_W^2)}{5}$$

$\approx 0.013(0.002$ @ LHC)

▷ strong cancellation between up and down quark contributions

III HADRONIC COLLISIONS

$p\bar{p}$ – 1.96 TeV

dominantly central production:

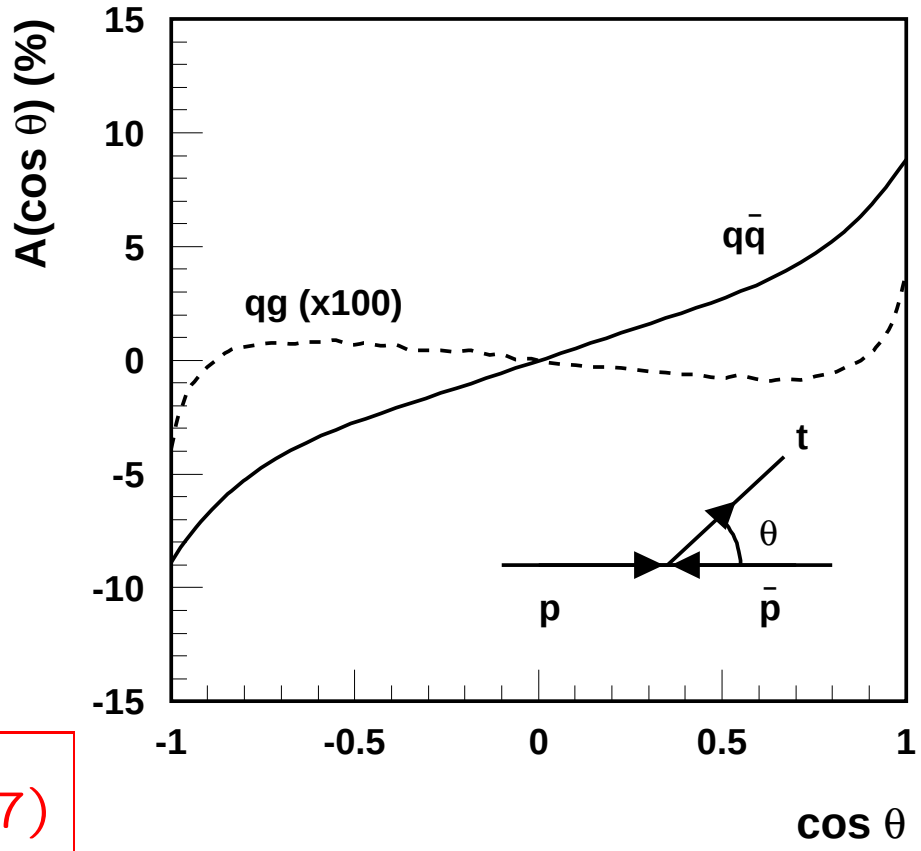
$$q\bar{q} \to t\bar{t}$$

partonic asymmetry

⇓

hadronic asymmetry

⇒ Integrated asymmetry



$$A_{Lab} = \frac{N(y_t > 0) - N(y_{\bar{t}} > 0)}{N(y_t > 0) + N(y_{\bar{t}} > 0)} = 0.056(7)$$

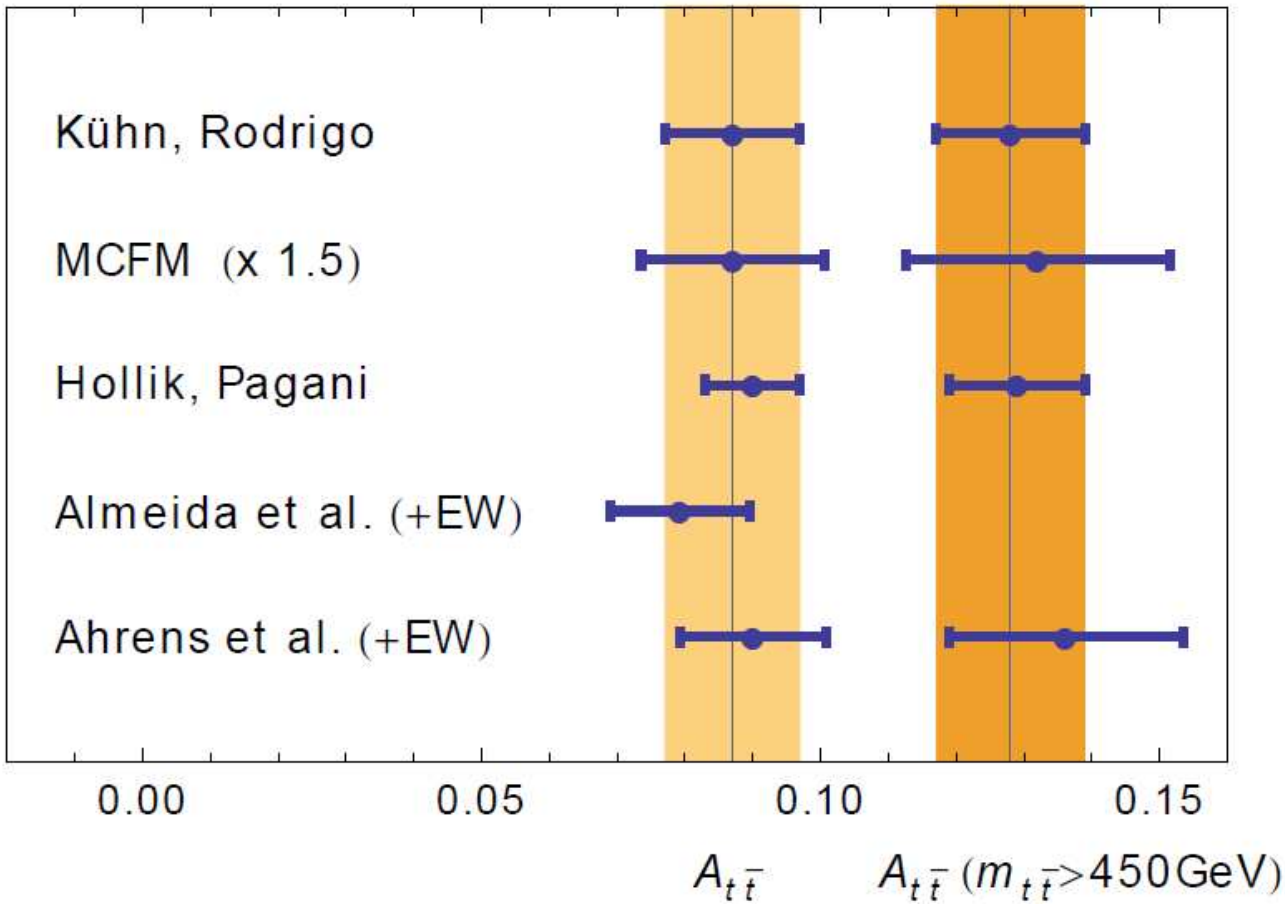
charge asymmetry ≡ forward-backward asymmetry

alternative:

$$A_{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} = 0.087(10) \qquad \Delta y = y_t - y_{\bar{t}}$$

(asymmetry in $t\bar{t}$ restframe $\approx$ partonic asymmetry)

- QCD-EW contribution $\Rightarrow$ factor 1.2 (JK, Rodrigo/ Hollik, Pagani)
- leading order asymmetry normalized relative to leading order cross section
- stable against NLL and NNLO threshold resummations (Almeida,.../ Ahrens,...)
- large corrections for $t\bar{t}g$ (Dittmaier, Uwer, Weinzierl) waiting for full NLO of $A_{t\bar{t}}$



- Main difference due to renormalization scale choice, the asymmetry is proportional to the strong coupling

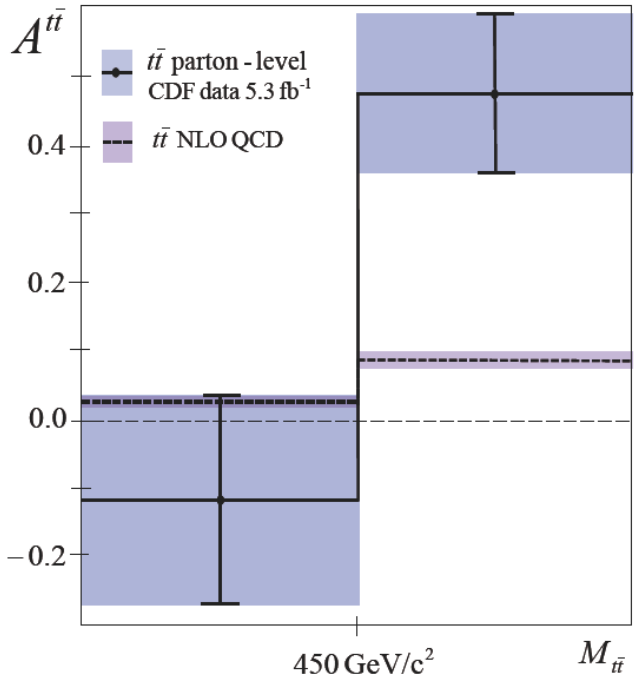
- small dependence on PDFs

Invariant mass dependent charge asymmetry

Since 2008, a systematic $1-2\sigma$ **positive** discrepancy with the SM (inclusive asymmetry)

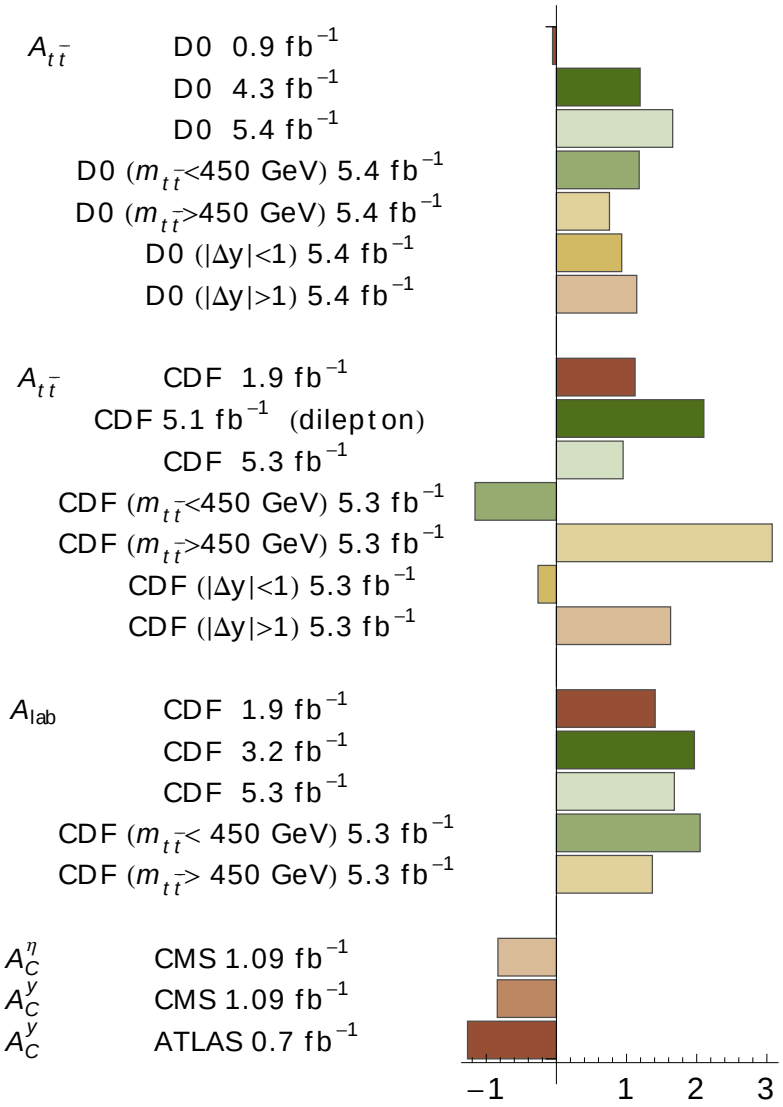
CDF [PRD83 (2011)112003 arXiv:1101.0034] $t\bar{t}$ rest frame 5.3fb^{-1}

$$A_{t\bar{t}}(m_{t\bar{t}} < 450\text{GeV}) = -0.116 \pm 0.146(\text{stat}) \pm 0.047(\text{syst})$$
$$A_{t\bar{t}}(m_{t\bar{t}} > 450\text{GeV}) = 0.475 \pm 0.101(\text{stat}) \pm 0.049(\text{syst})$$



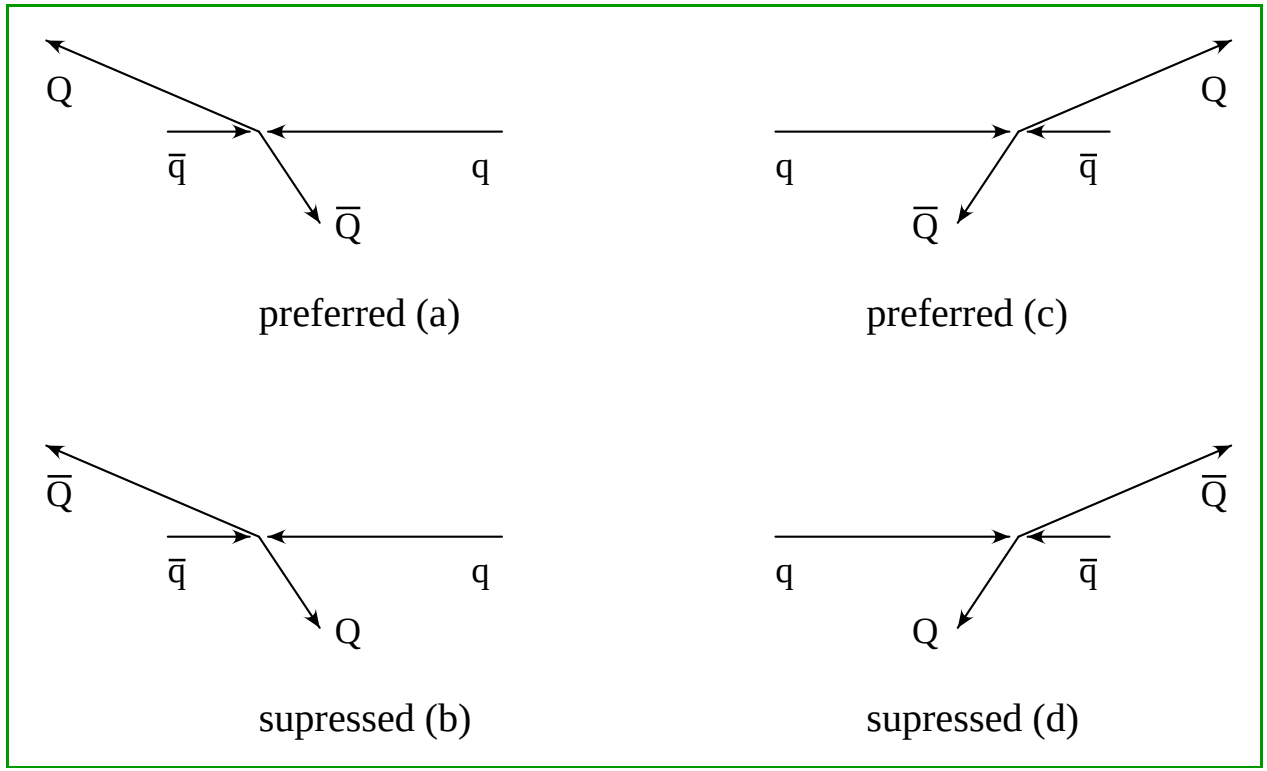
- below 450 GeV: negative asymmetry but still compatible with the SM within 1σ
- above 450 GeV: positive asymmetry disagrees with the SM at 3.4σ
- The deviation from the SM in the lab frame is not as significant!!!

Tevatron (and LHC) summary



pp – 14 TeV

- no forward backward asymmetry
- slight difference between rapidity distributions of Q and $\bar{Q}$ from (small) admixture of $q\bar{q}$ processes



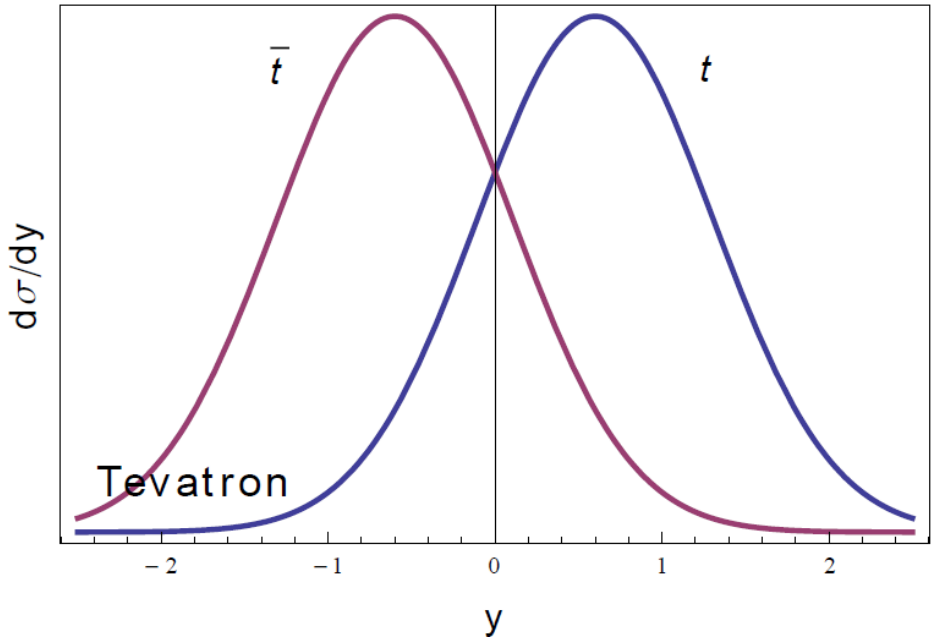
$\Rightarrow$ more t at large rapidity

$\Rightarrow$ more $\bar{t}$ at small rapidity

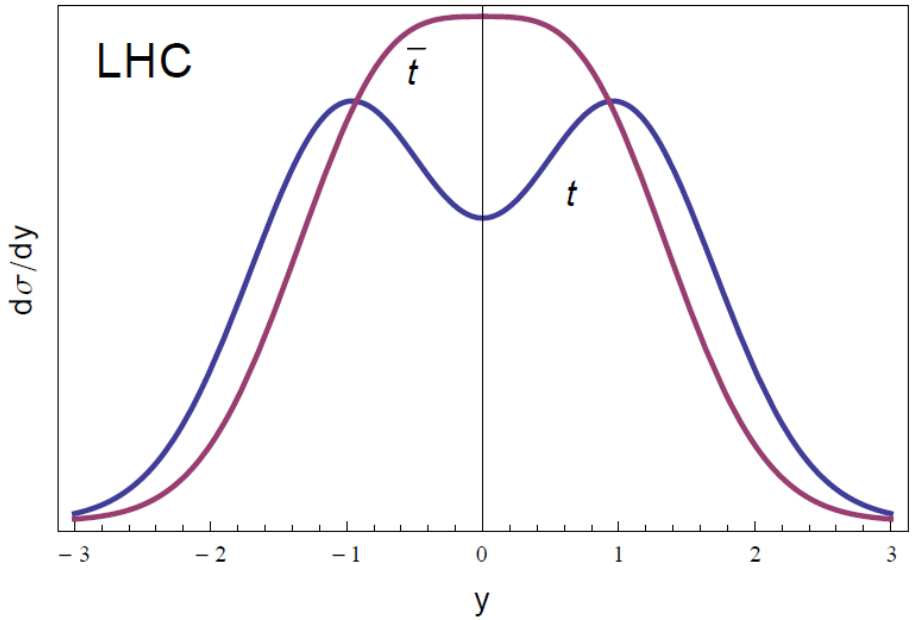
main effect in regions of small cross section

JK, Rodrigo (1998)

Tevatron



LHC



(qualitative picture, exaggerated scales)

Quantitative

$$A_{\rm LHC}^{\Delta} \equiv \frac{N(\Delta>0)-N(\Delta<0)}{N(\Delta>0)+N(\Delta<0)}\,;$$

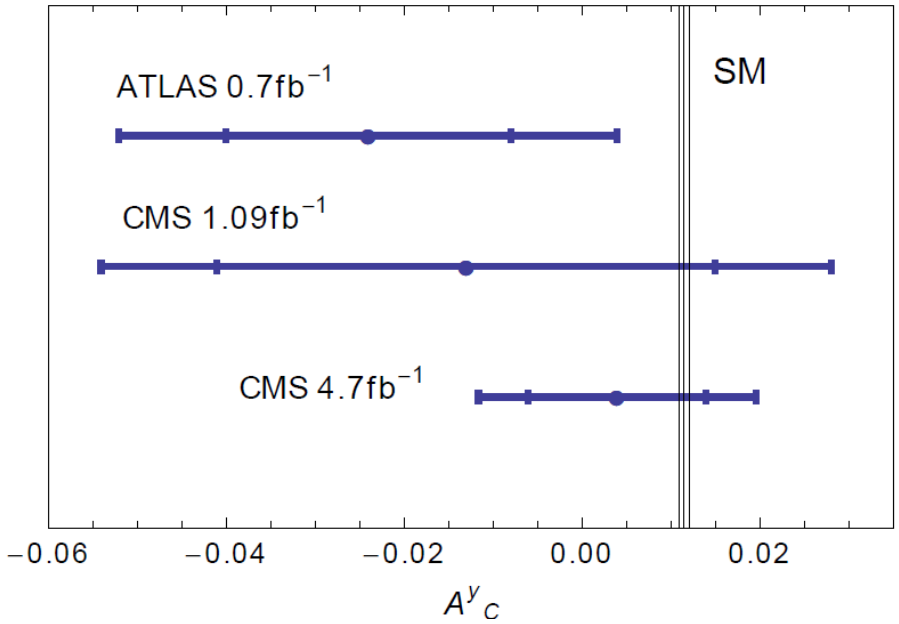
$\Delta = |y_t| - |y_{\bar{t}}|$ or $y_t^2 - y_{\bar{t}}^2$

$=0.0115(6)$ JK, Rodrigo JHEP 1201(2012)063

$-0.024 \pm 0.016 \pm 0.023$ atlas-conf-2011-106

$-0.013 \pm 0.028\,^{+0.029}_{-0.031}$ cms (1112.5100)

$0.004 \pm 0.010 \pm 0.012$ cms-pas-top-11-030

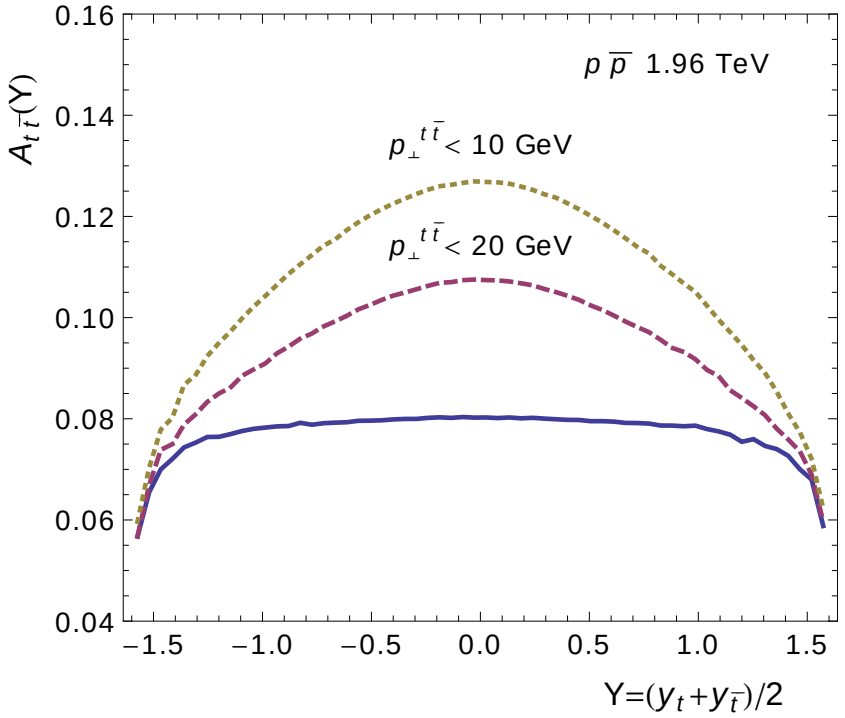


perspectives: 100fb^{-1} : $\delta A \sim 2-3$ permille

Cutoff-dependence:

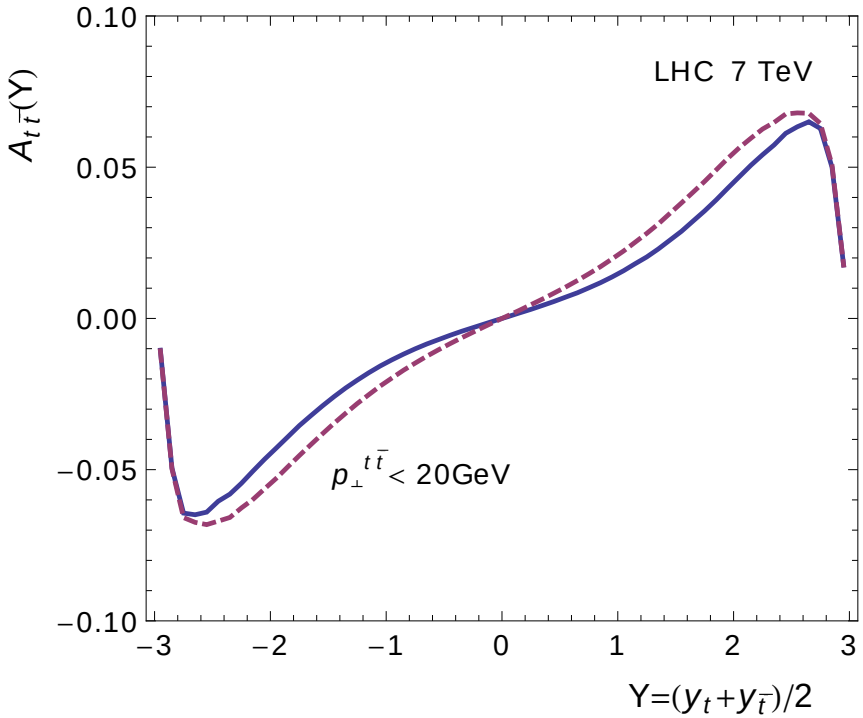
cut on $p_\perp(t\bar{t}) = p_\perp(g)$ enhances asymmetry

consider $A_{t\bar{t}}(Y) = \frac{N(\Delta y>0)-N(\Delta y<0)}{N(\Delta y>0)+N(\Delta y<0)}$ for $Y = \frac{y_t+y_{\bar{t}}}{2}$ fixed and $\Delta y = y_t - y_{\bar{t}}$



solid line: no cut on $p_\perp^{t\bar{t}}$,
dotted/dashed line: similar effects on integrated asymmetry!

$p_\perp^{\max} = 10$ GeV / 20 GeV.



solid line: no cut on $p_\perp^{t\bar{t}}$,
dashed line: $p_\perp^{\max} = 20$ GeV.

Summary

- ⋆ forward backward asymmetry for t production at TEVATRON $\sim 7\%$
- ⋆ important test of production mechanism
- ⋆ unique possibility for $p\bar{p}$ collider
- ⋆ differences between t and $\bar{t}$ distributions at LHC mainly in regions of small cross section (large rapidity!)
- ⋆ Large statistics anticipated for LHC
- ⋆ strong sensitivity to cuts on p_T distribution