

# Asymmetries in $t \bar{t}$ gamma production

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# The $t\bar{t}$ asymmetry at the LHC

$q\bar{q}$  initial state is swamped  
by the  $gg$  initial state

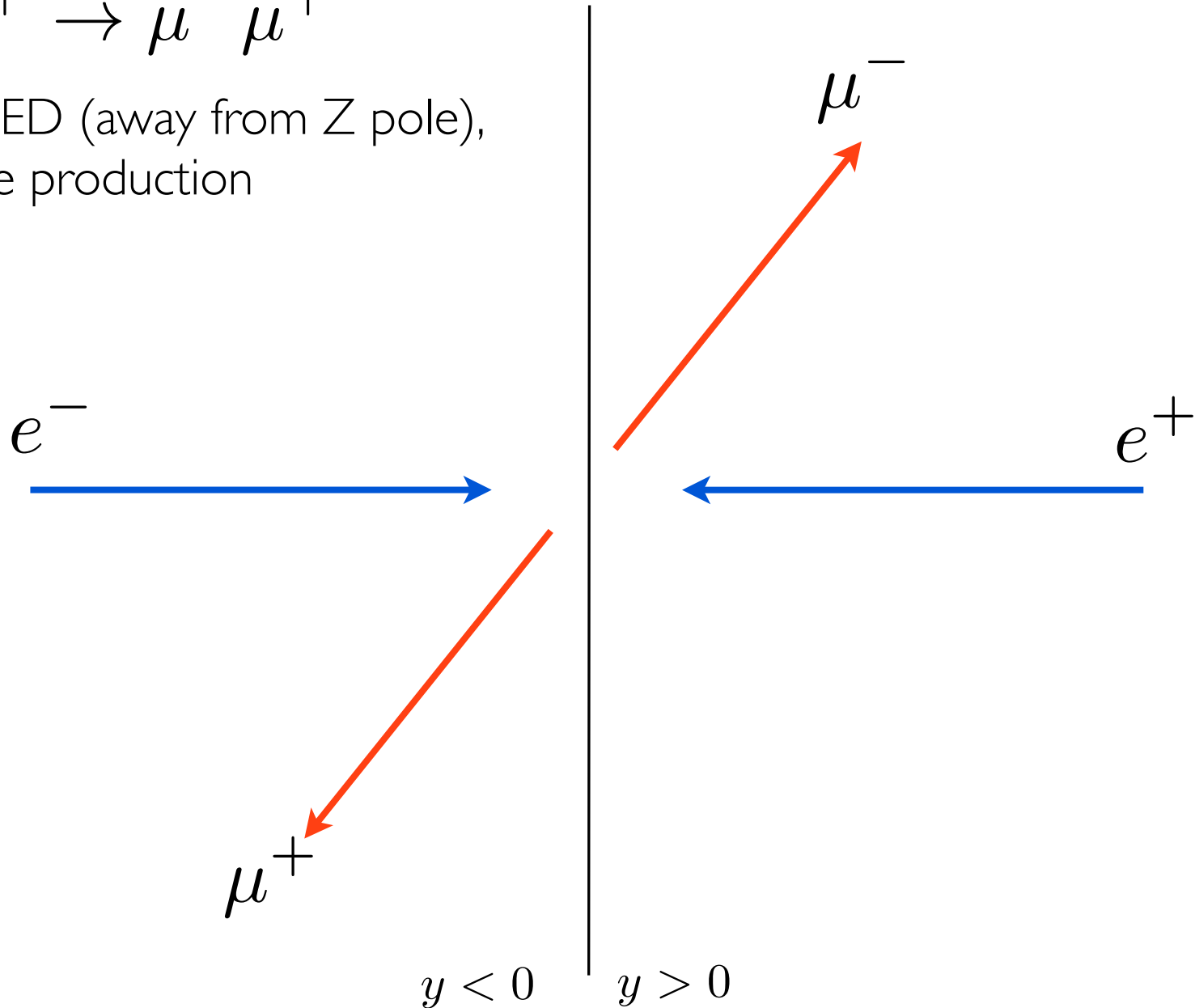
basic idea - use the photon  
to 'tag' the quark initial state

new mechanisms contribute  
to the asymmetry

# Charge asymmetries

$$e^- e^+ \rightarrow \mu^- \mu^+$$

pure QED (away from Z pole),  
inclusive production



# Charge asymmetries

$$A = \frac{N(y_{\mu^-} > 0) - N(y_{\mu^-} < 0)}{N(y_{\mu^-} > 0) + N(y_{\mu^-} < 0)}$$

$$e^- e^+ \rightarrow \mu^- \mu^+ \quad A > 0$$

inclusive production

$$e^- e^+ \rightarrow \mu^- \mu^+ \gamma \quad A < 0$$

more exclusive, radiation  
required

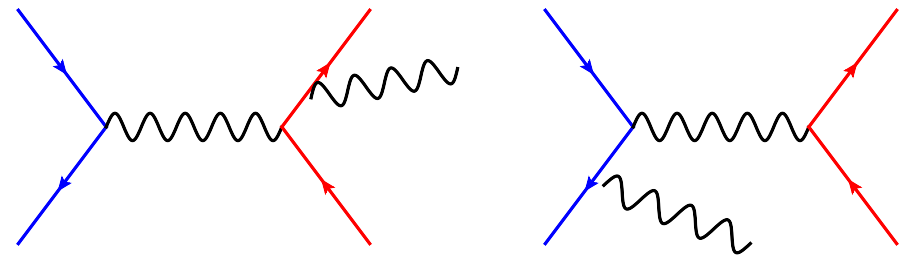
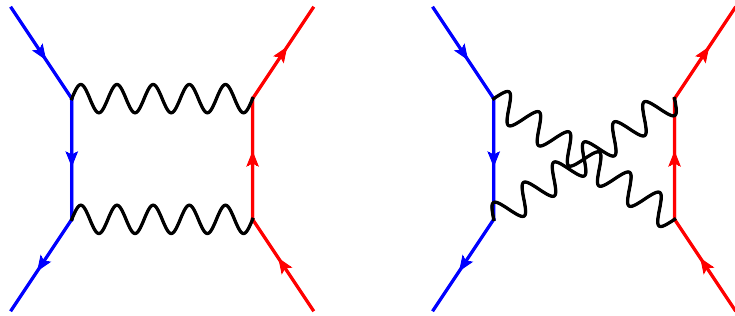
# Charge asymmetries

Berends, Gaemers, Gastmans '73  
Berends, Kleiss, Jadach, Was '83

The effect comes in at NLO

Virtual

Real



Large  $A > 0$   
contribution

Large  $A < 0$   
contribution

Small  $A > 0$  charge asymmetry

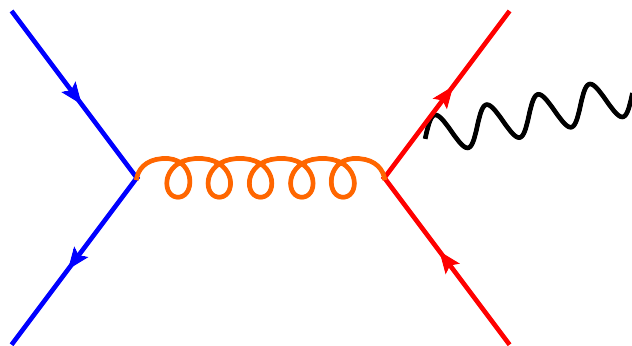
$$q\bar{q} \rightarrow t\bar{t}$$

QCD asymmetry works in exactly the same way

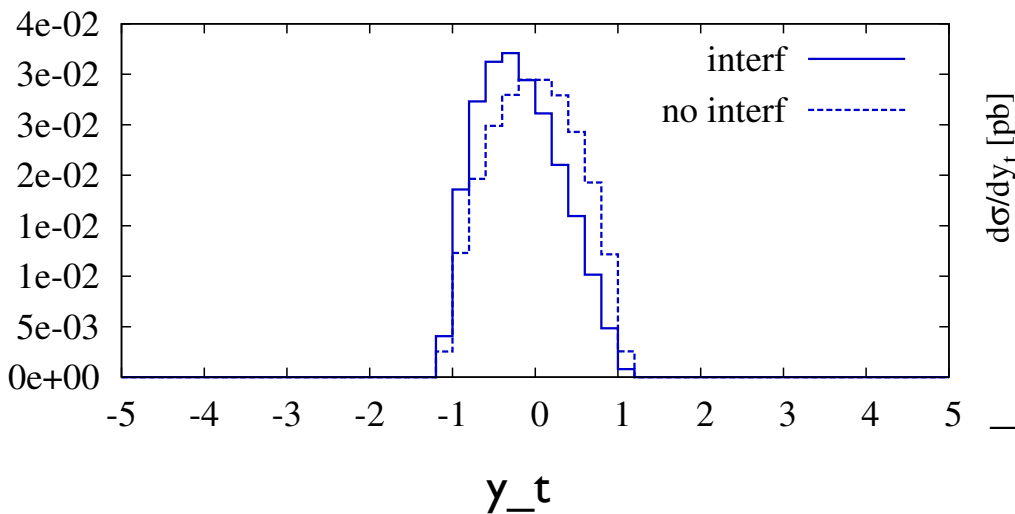
Kuhn, Rodrigo '98

$$q\bar{q} \rightarrow t\bar{t}\gamma$$

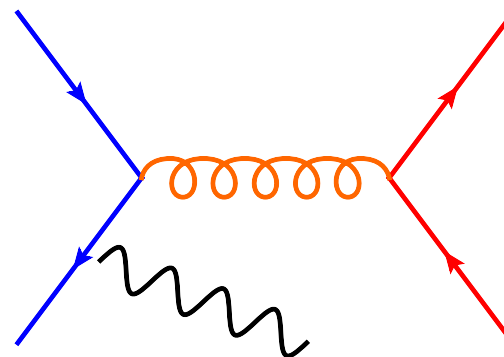
Large LO QED asymmetry



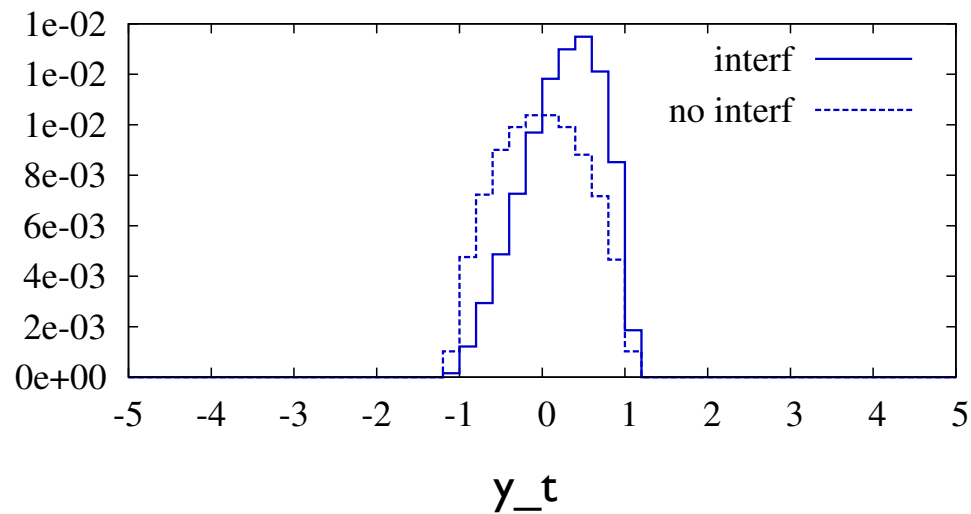
u ub > t tb a ; 300 GeV x 300 GeV



**A=-29%**



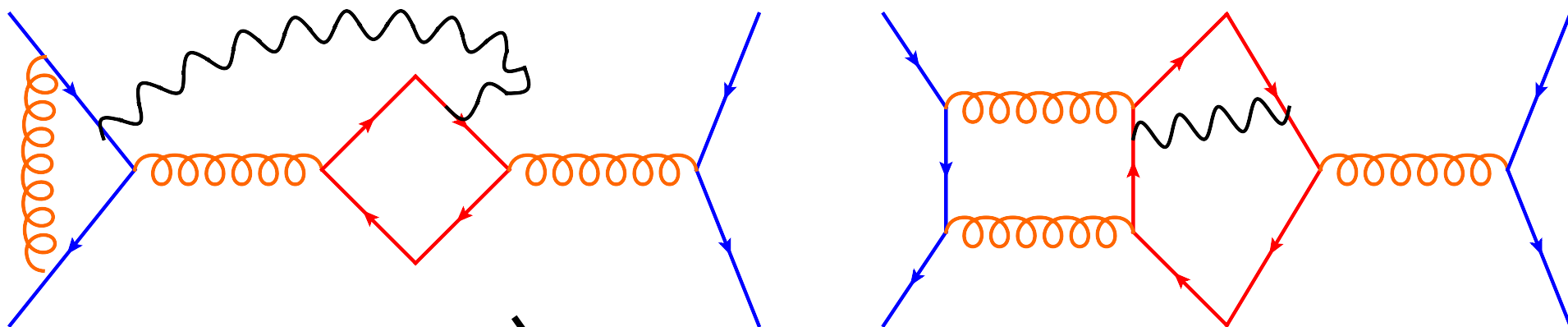
d db > t tb a ; 300 GeV x 300 GeV



**A=40%**

$$q\bar{q} \rightarrow t\bar{t}\gamma$$

NLO asymmetry



“QCD correction  
to LO”-like

“tt  
asymmetry”-  
like

$$A = A_{\text{LO}} Q_q Q_t + \alpha_S \left( A_{\text{NLO}} Q_q Q_t + A'_{\text{NLO}} Q_q^2 + A''_{\text{NLO}} Q_t^2 \right)$$

$$pp \rightarrow t\bar{t}\gamma$$

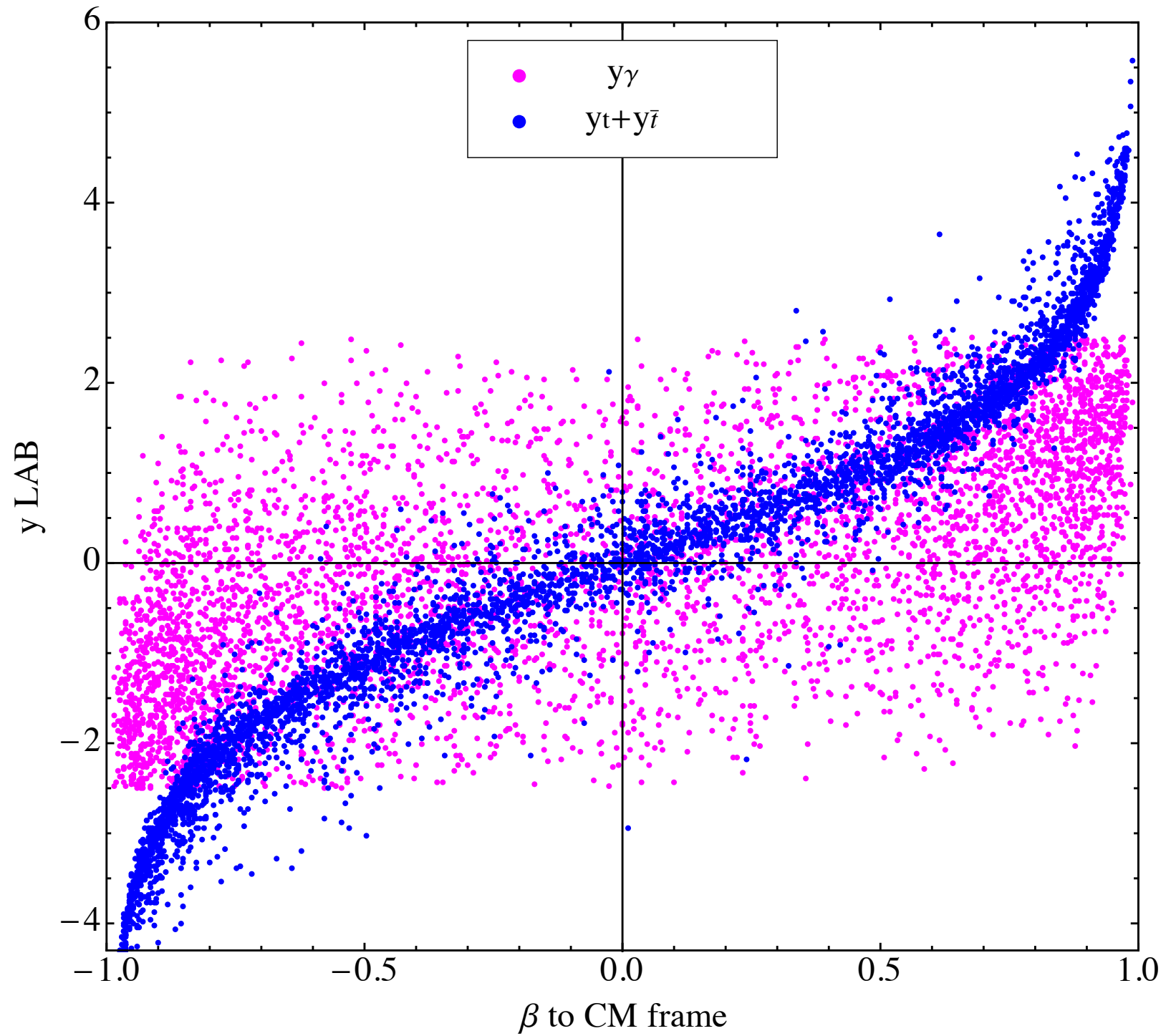
NLO asymmetry

$$A_c = \frac{N(|y_t| > |y_{\bar{t}}|) - N(|y_{\bar{t}}| > |y_t|)}{N(|y_t| > |y_{\bar{t}}|) + N(|y_{\bar{t}}| > |y_t|)}$$

Increase proportion of  
 $q\bar{q}$  initial state

Increase correct guess  
of  $q$  direction





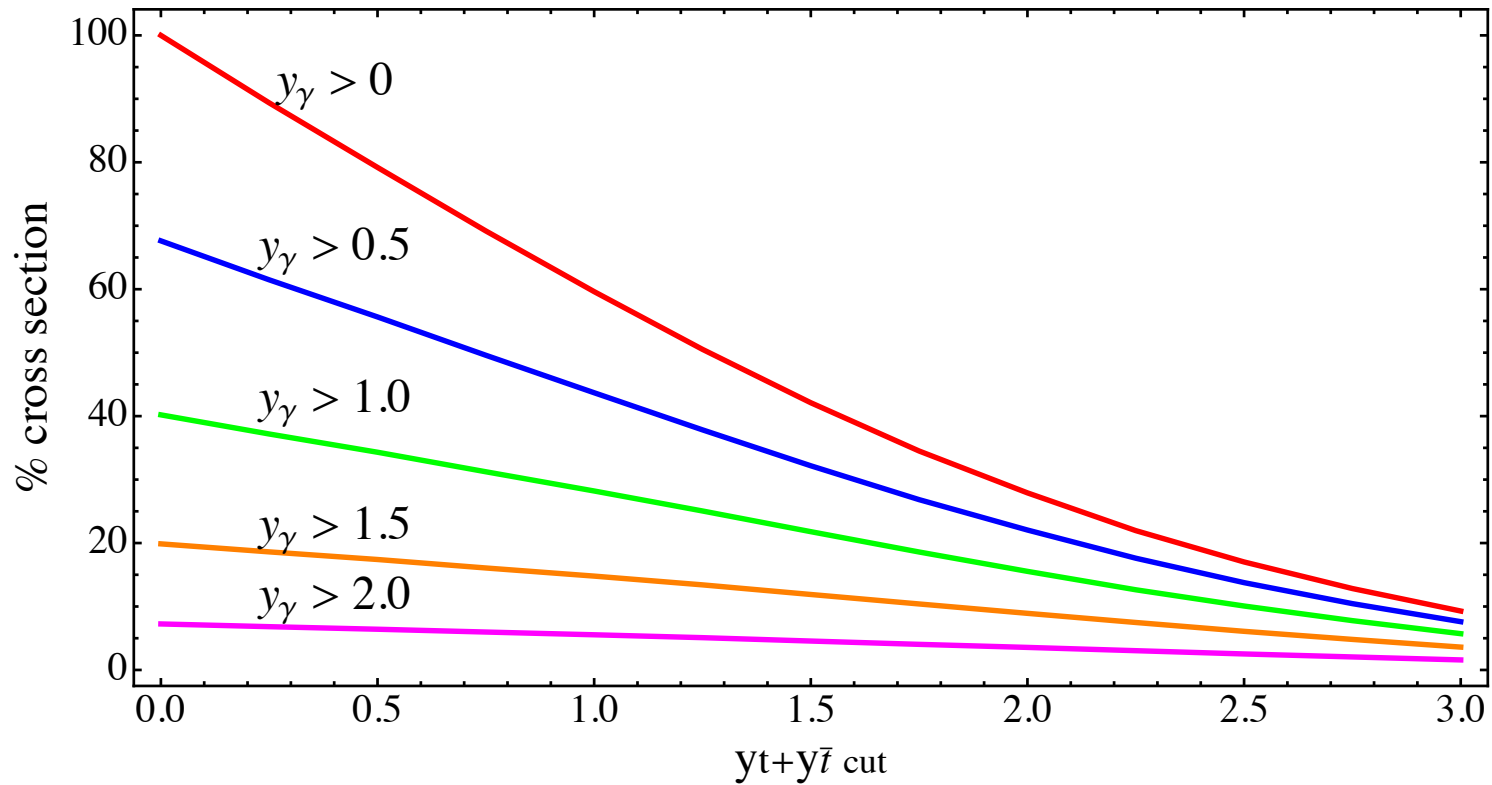
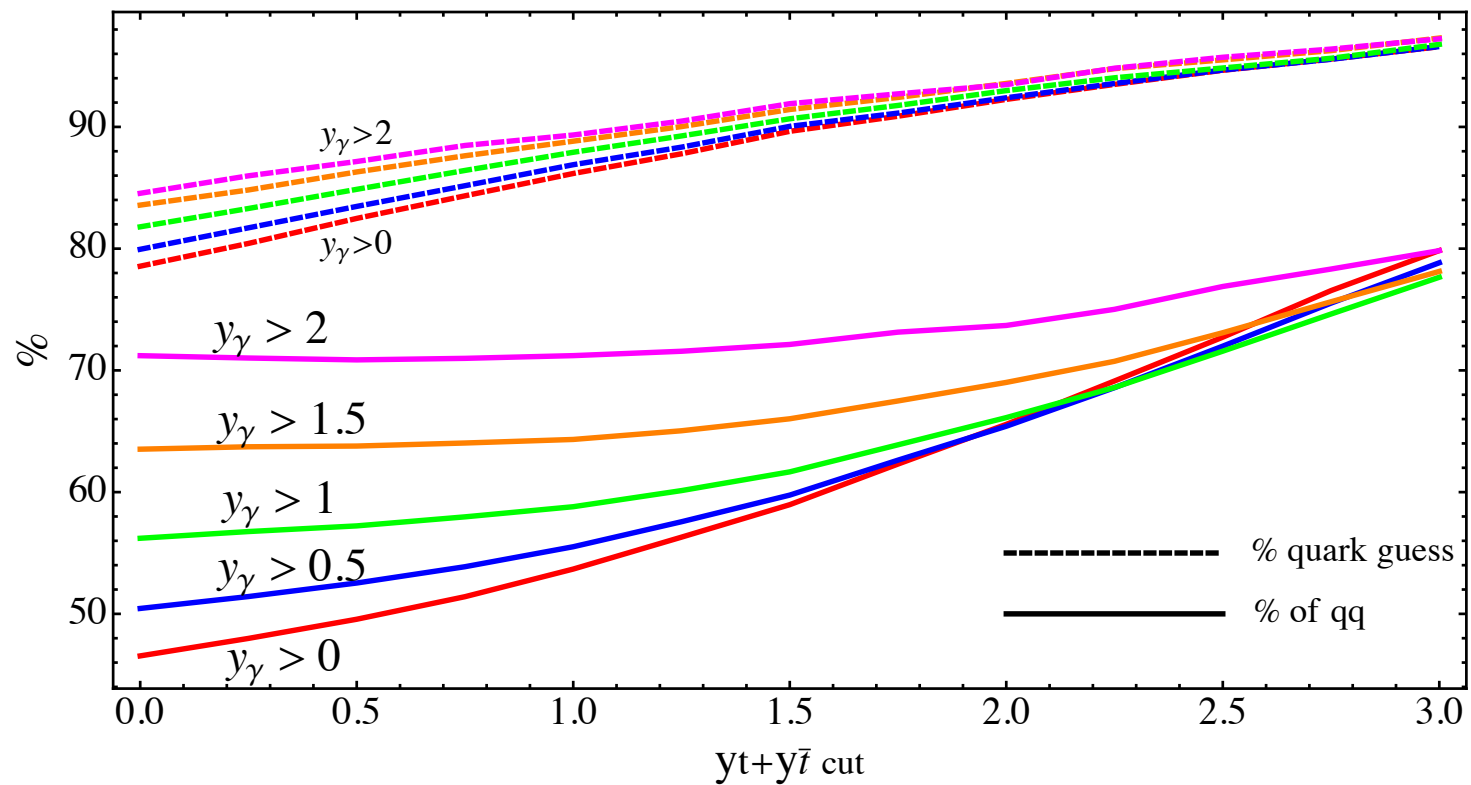


Table prepared using  
aMC@NLO:

$p p \rightarrow t t^{\sim} a$  [QCD]

\* Cut  $p_{t\gamma} > 20$  GeV

\* Cut  $|y_{\gamma}| < 2.5$

\* Frizione isolation (params.  $E_h=1$ ,  $R=0.7$ )  
modify cuts.f or v4 update (soon)

# Run at 8 TeV

uncertainties shown are pdf and scale

LO

NLO

$\sigma$  (pb)

$A$  (%)

$\sigma$  (pb)

$A$  (%)

no further cuts	0.76(30)	-5.5(3)	0.80(6)	- 2.2(3)
$ y_t  +  y_{\bar{t}}  > 1$	0.53(20)	-7.2(4)	0.56(4)	- 2.7(3)
$ y_t  +  y_{\bar{t}}  > 2$	0.34(12)	-9.0(5)	0.36(3)	- 3.7(4)
$m_{t\bar{t}} > 450\text{GeV}$	0.54(20)	-5.6(4)	0.54(4)	- 0.1(3)
$m_{t\bar{t}} > 650\text{GeV}$	0.23(9)	-5.3(4)	0.23(2)	+ 2.2(4)

# The $t\bar{t}$ photon asymmetry at the LHC

new asymmetry to look  
for experimentally

complimentary to the  
usual  $t\bar{t}$  asymmetry

brings new sensitivity to  
BSM physics