Top quark charge asymmetry and polarisation in $t\bar{t}W$ production at the LHC

Marco Zaro, LPTHE - UPMC Paris VI

in collabortion with
F. Maltoni, M. Mangano, I. Tsinikos, arXiv:1406.3262

GGI@Florence

September 18, 2014

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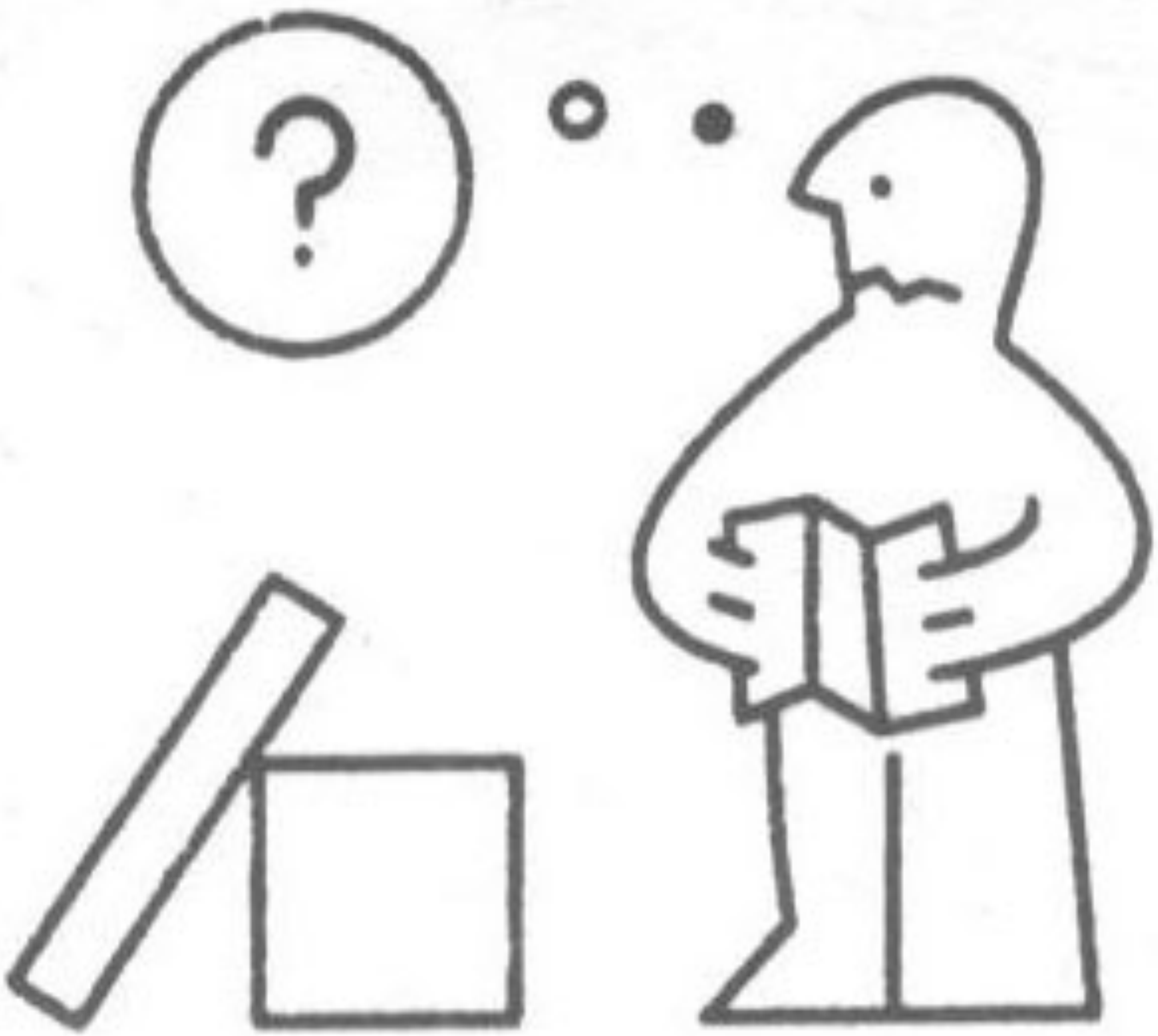
Outline:

- Charge asymmetries at colliders: how to?
- The top-quark asymmetry at hadron colliders
- Enhancing the top asymmetry at the LHC
- W-assisted top asymmetry at the LHC
- Polarisation effects
- A look beyond the SM
- Conclusions

Charge asymmetries at colliders: how to?



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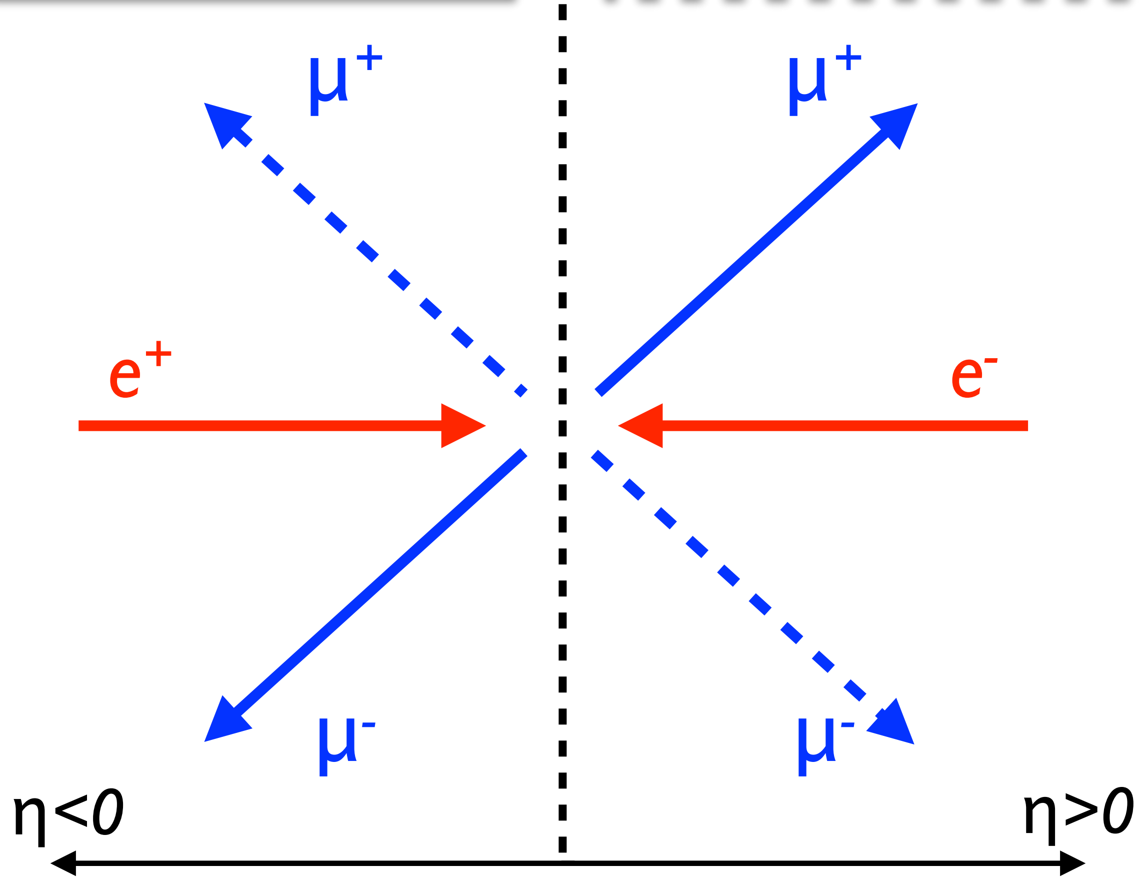

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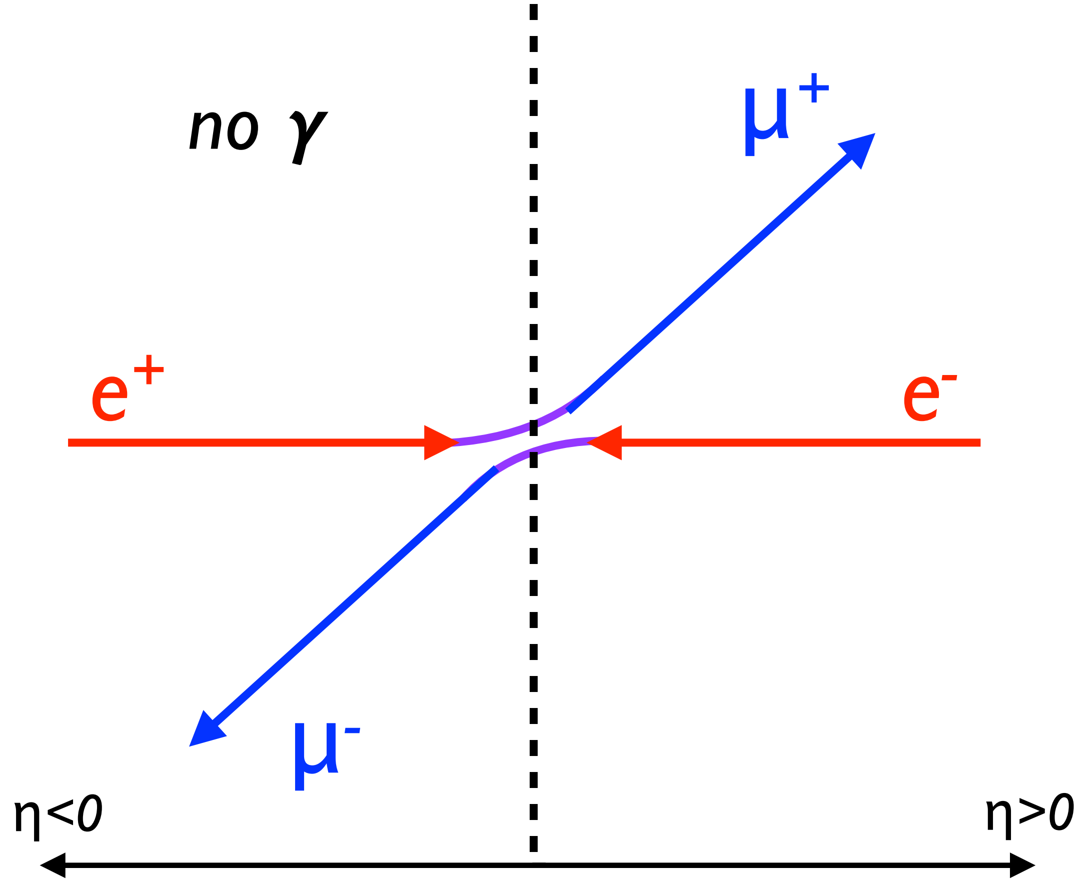

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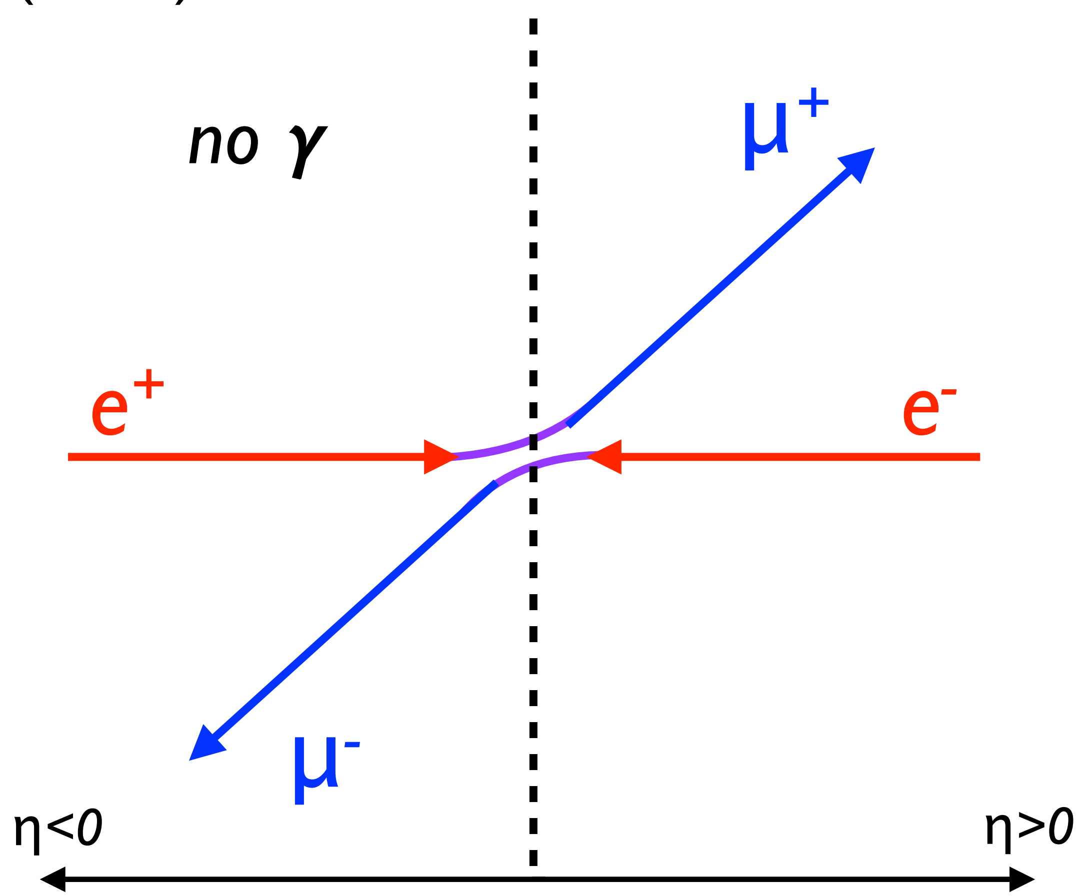

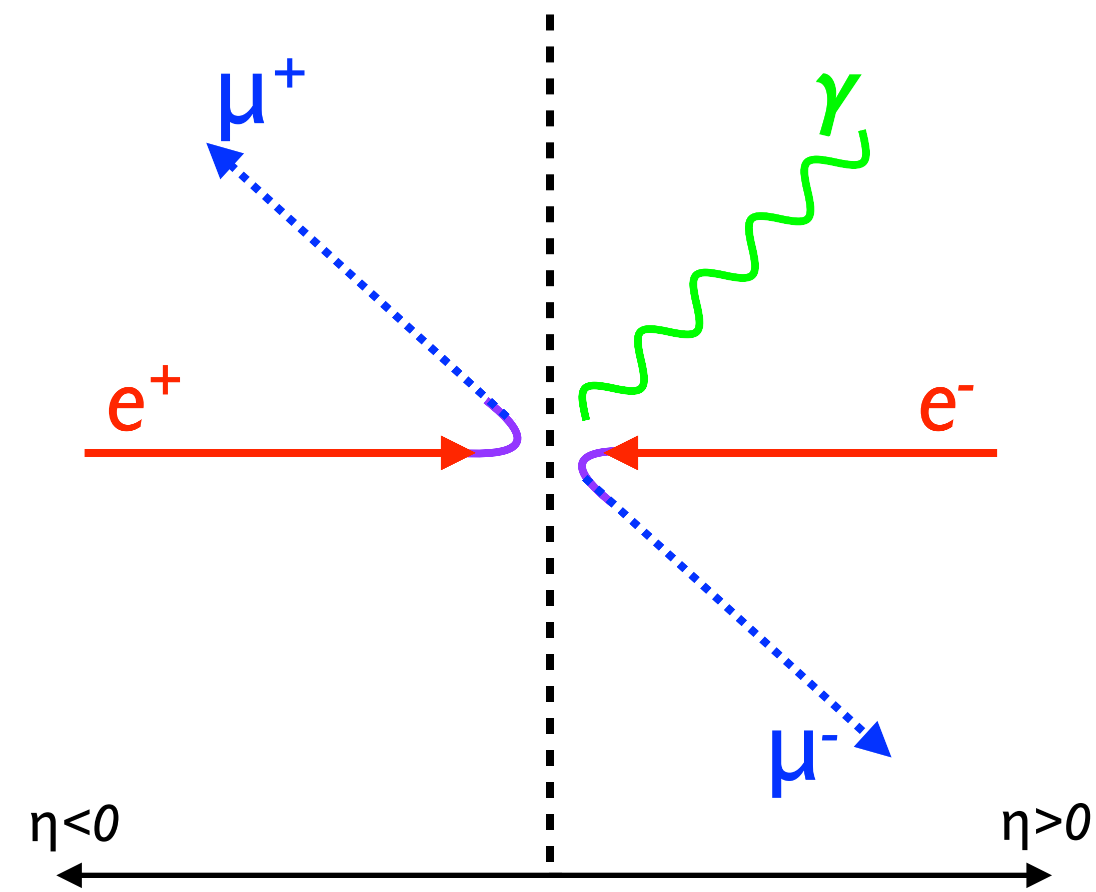

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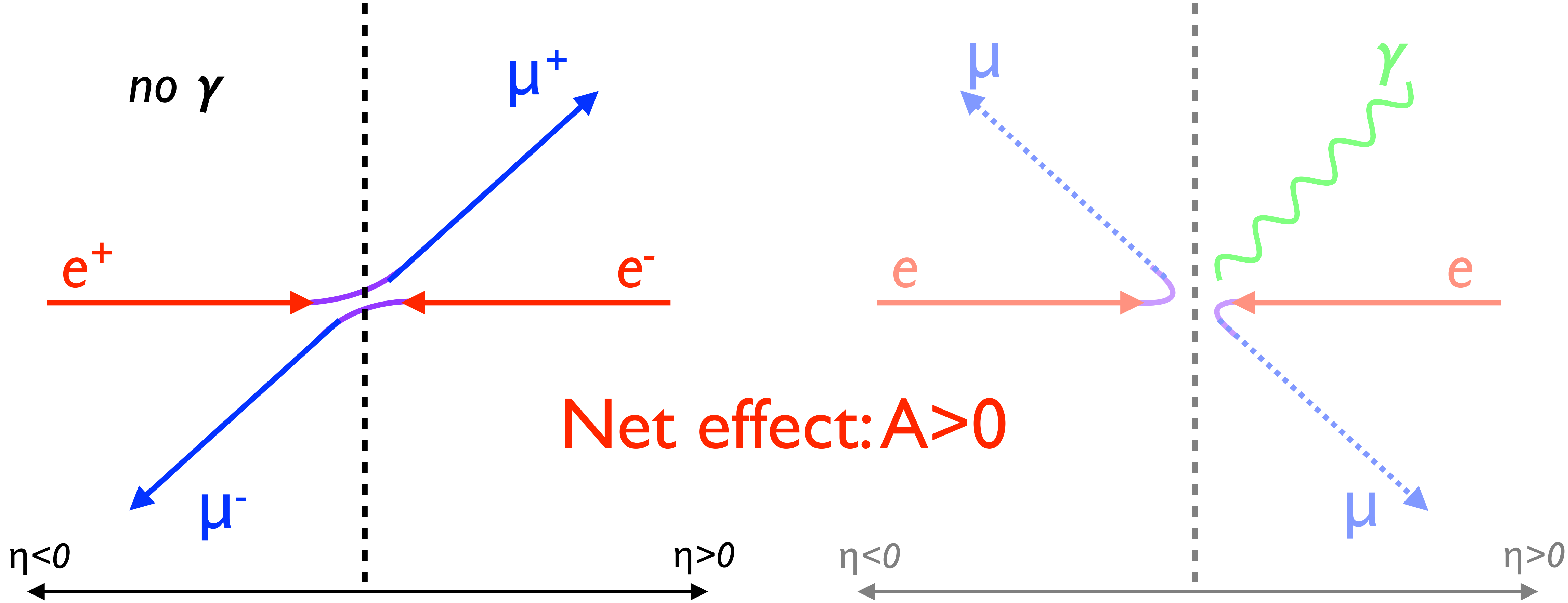

Net effect: A>0

From charge to colour

(more details in J.H.Kuhn, G.Rodrigo. arXiv:hep-ph/9807420)

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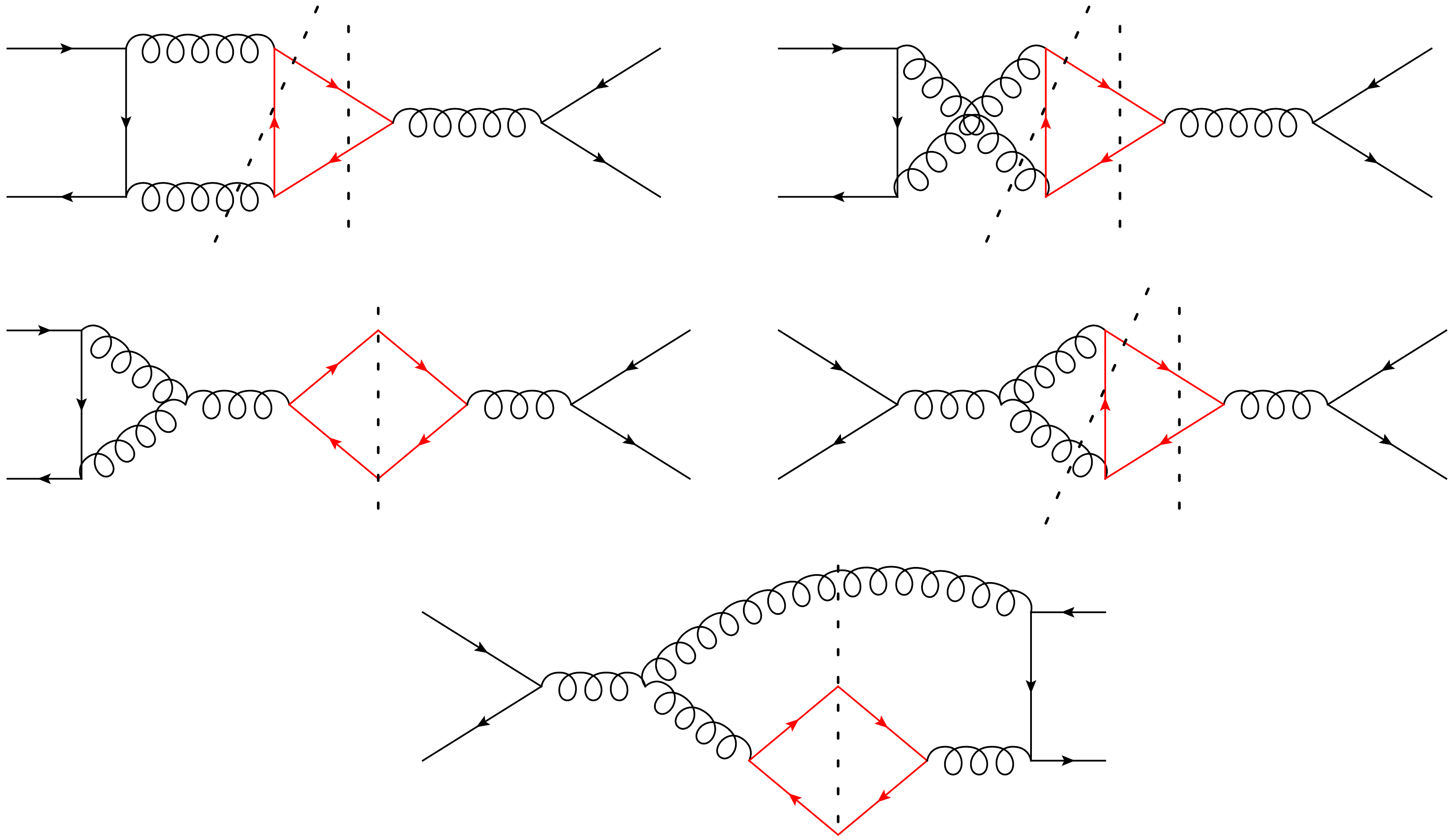

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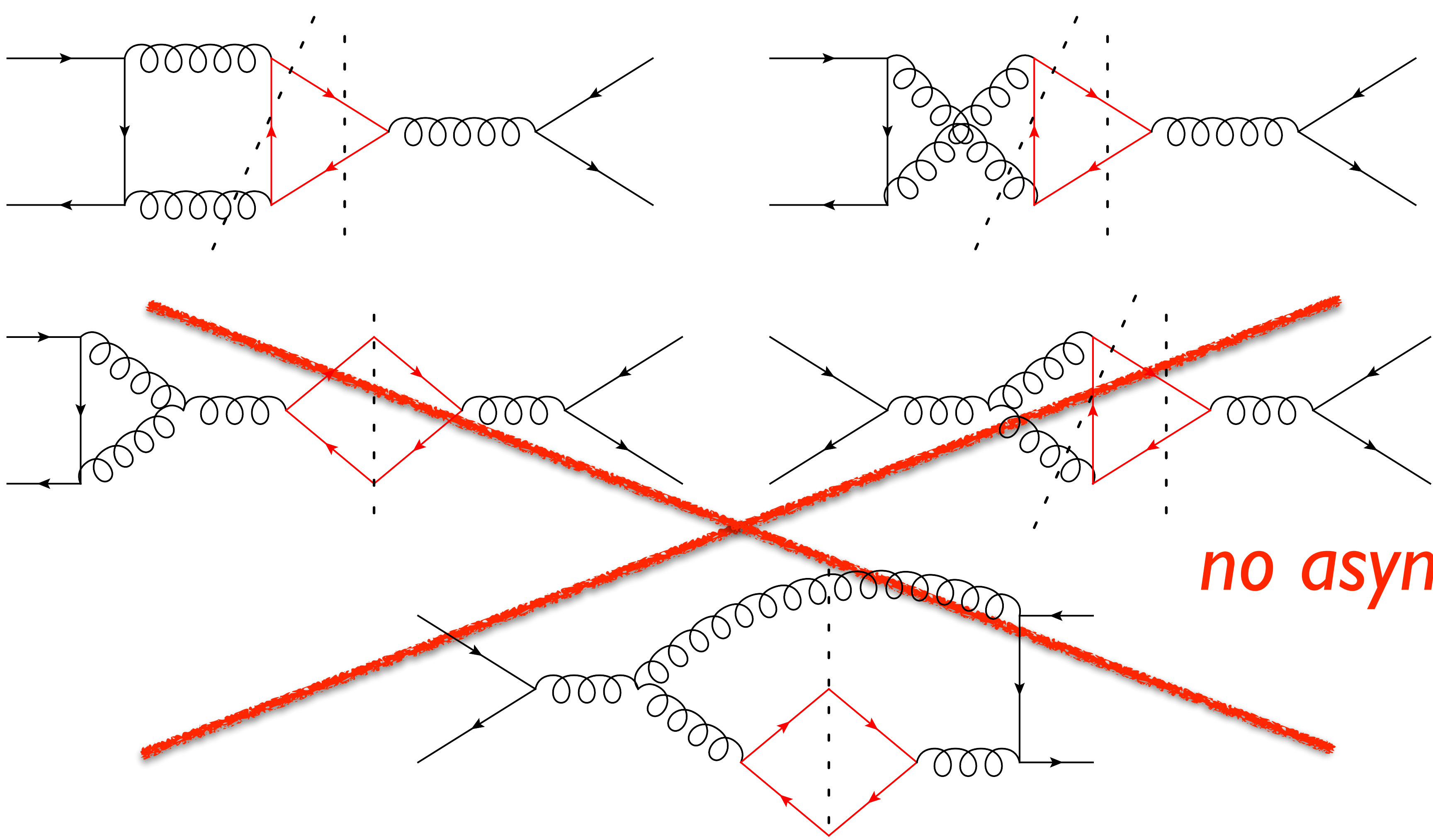

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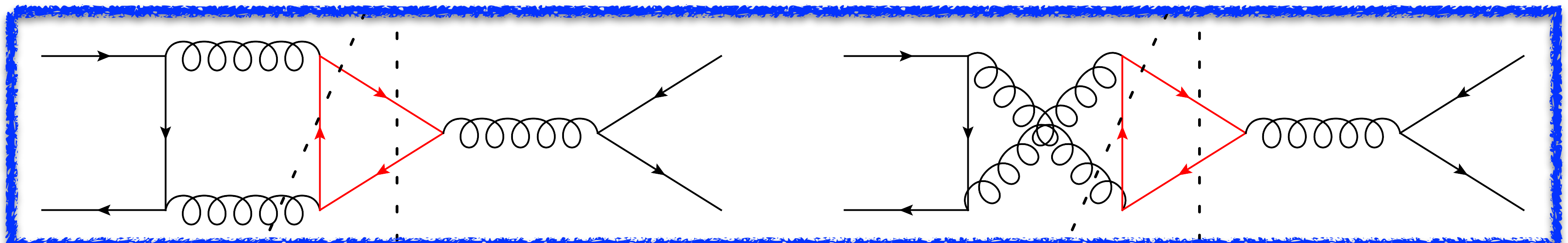

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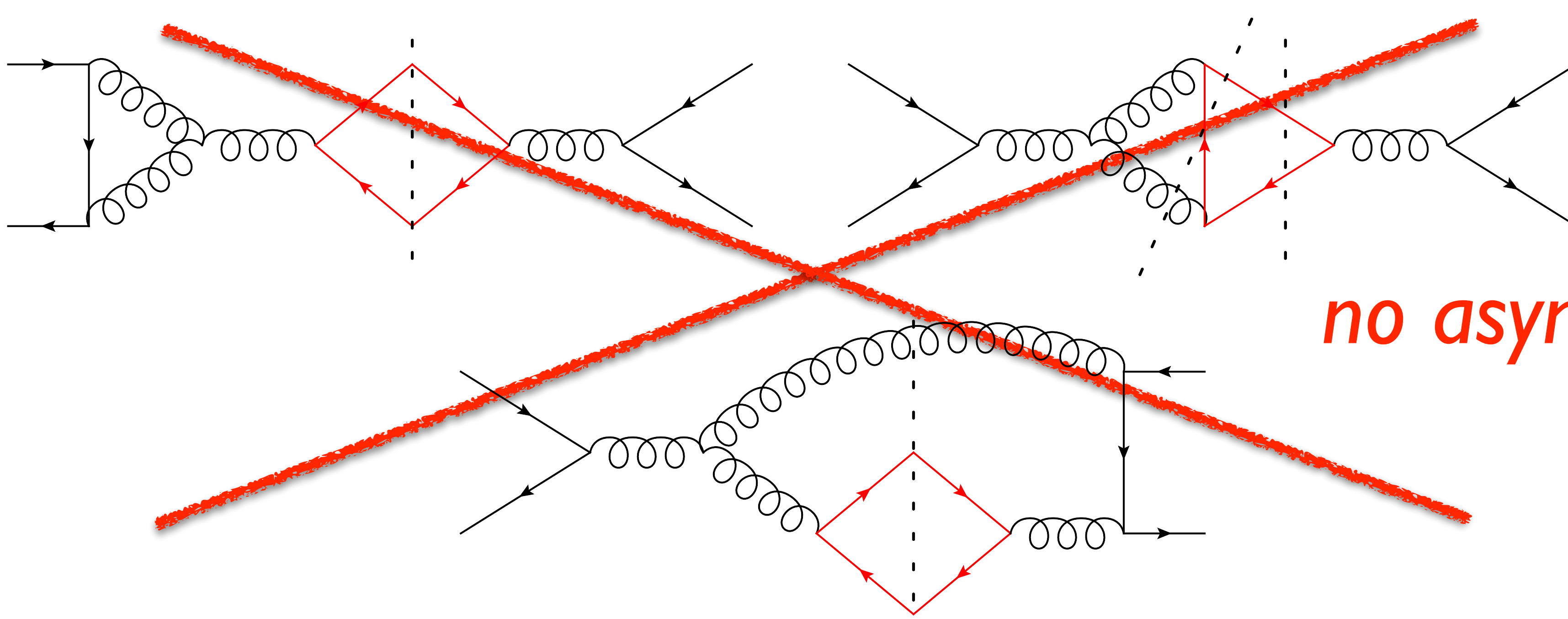

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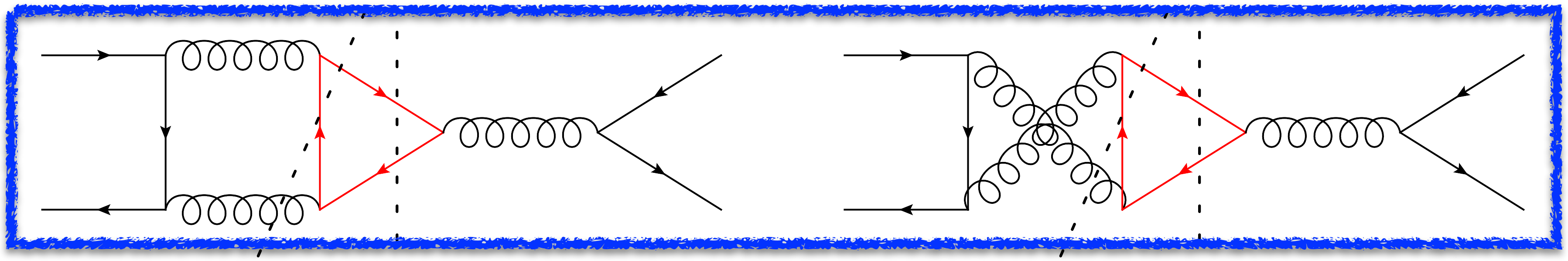

asymmetry from d^2_{abc}

  - QCD asymmetry can be related to the QED one by replacing

$$\alpha_e Q_q Q_Q \to \frac{d^2_{abc}}{16 N_C T_F C_F}\alpha_s = \frac{5}{12}\alpha_s$$

The top-quark asymmetry at hadron colliders

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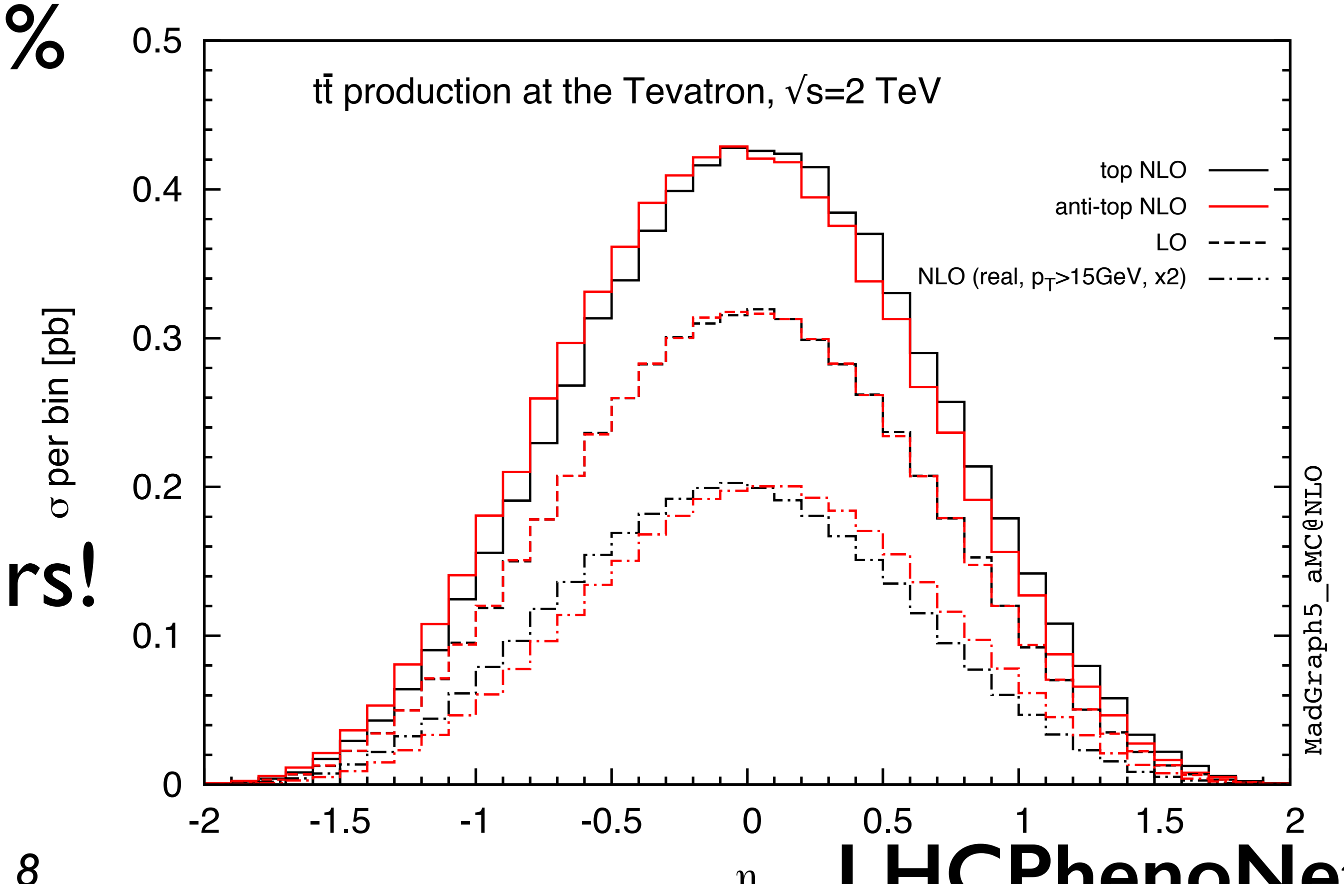
  - p mostly contains quarks, $\bar{p}$ mostly anti-quarks
  - gg (symmetric) contribution is small (10% of the x-sect)
  - SM prediction: A_t= 8.8±0.6 %
  - Measured values:
    - CDF: A_t=16.4±4.7 %
    - D0: A_t=19.6±6.5 %
  - 2σ tension
    - A manna for model builders!



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Top quark asymmetry at the Tevatron

- QCD as colliders by looking
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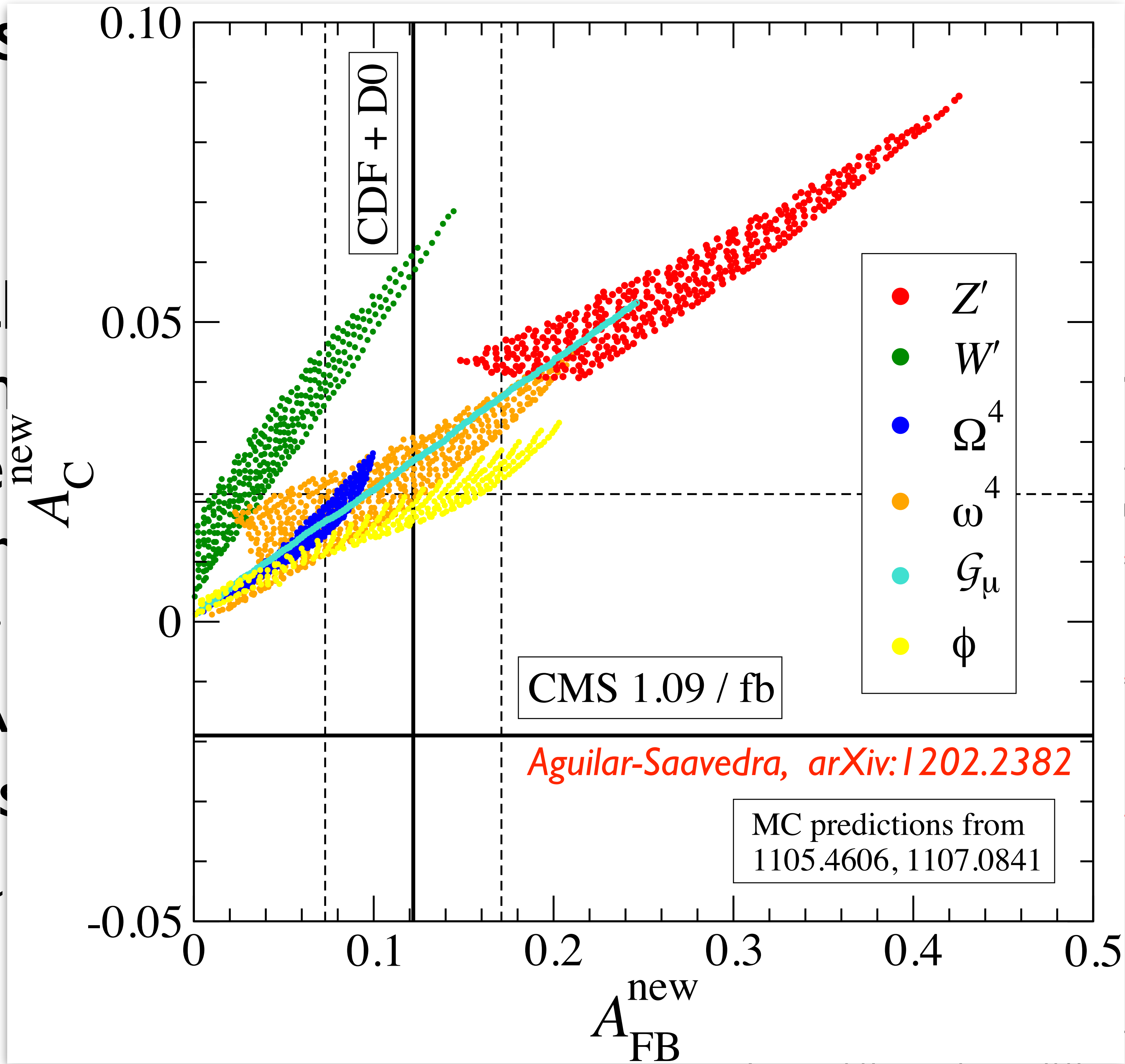

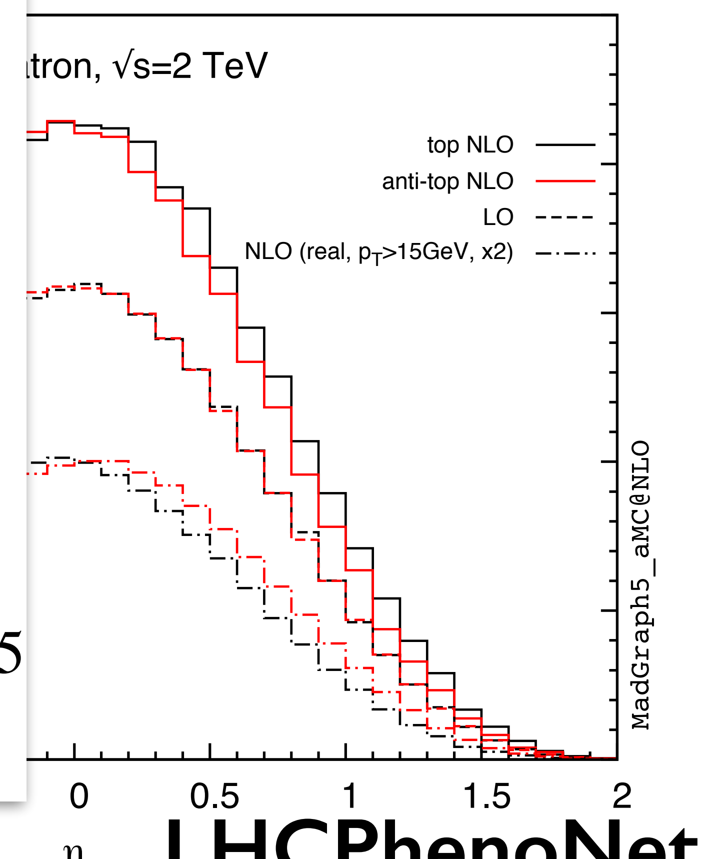

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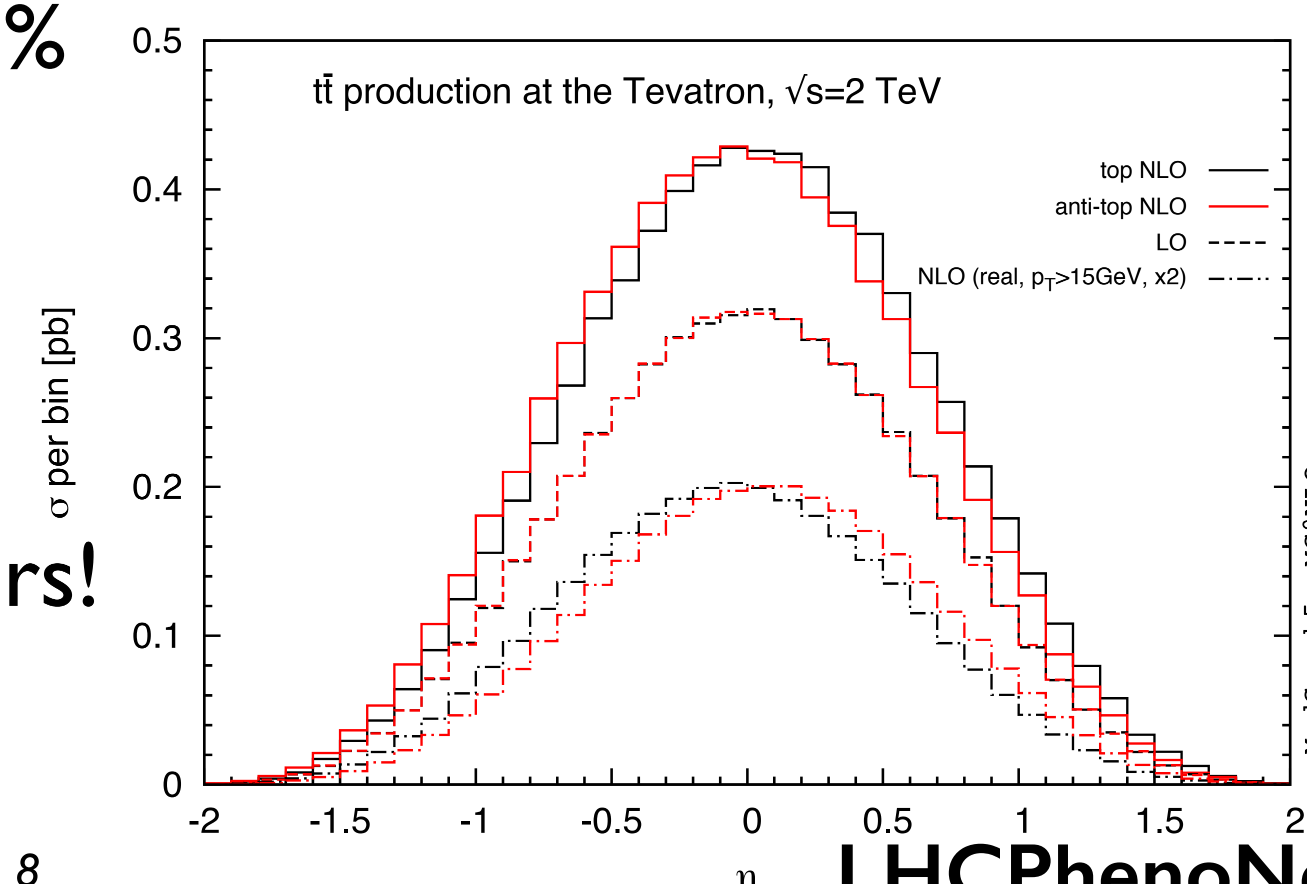

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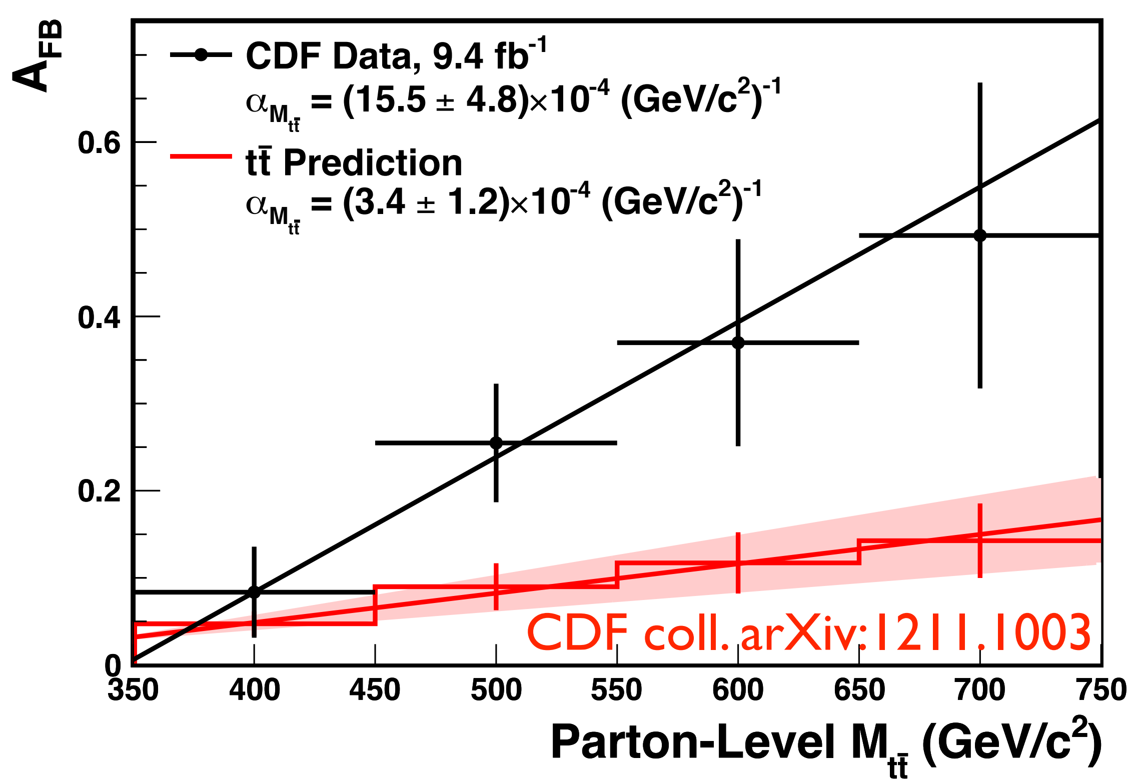
Top quark asymmetry at the Tevatron

- Top asymmetry mass dependence also deviates from SM predictions
  - Stronger deviations for larger $t\bar{t}$ invariant masses



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- Initial state is symmetric (but quarks are harder than antiquarks):
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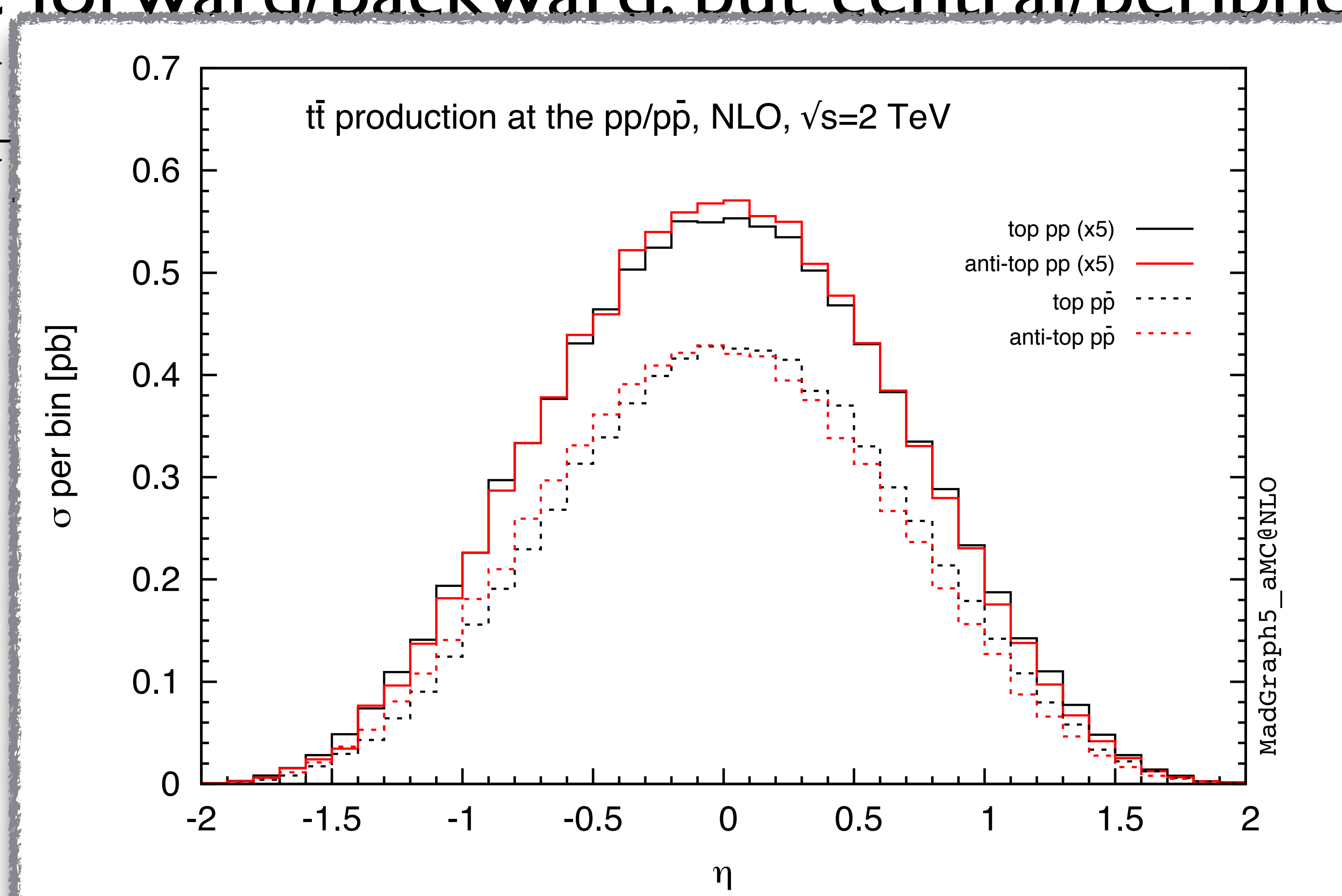

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check CMS-PAS-TOP-12-010,
ATLAS-CONF-2012-057,
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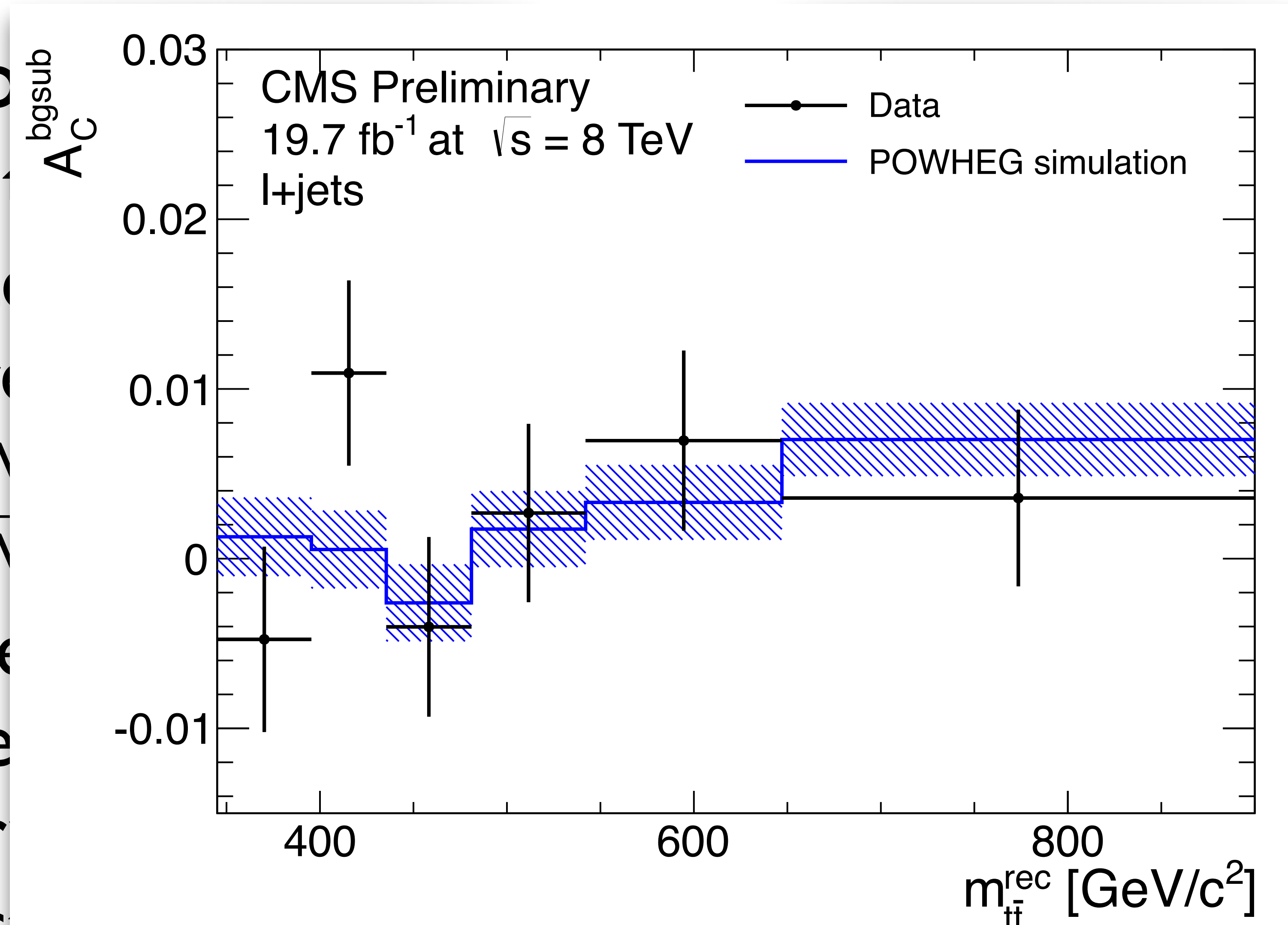

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Enhancing the top asymmetry at the LHC

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Look for $t\bar{t}$ production in association with "something" that prefers coupling to quarks

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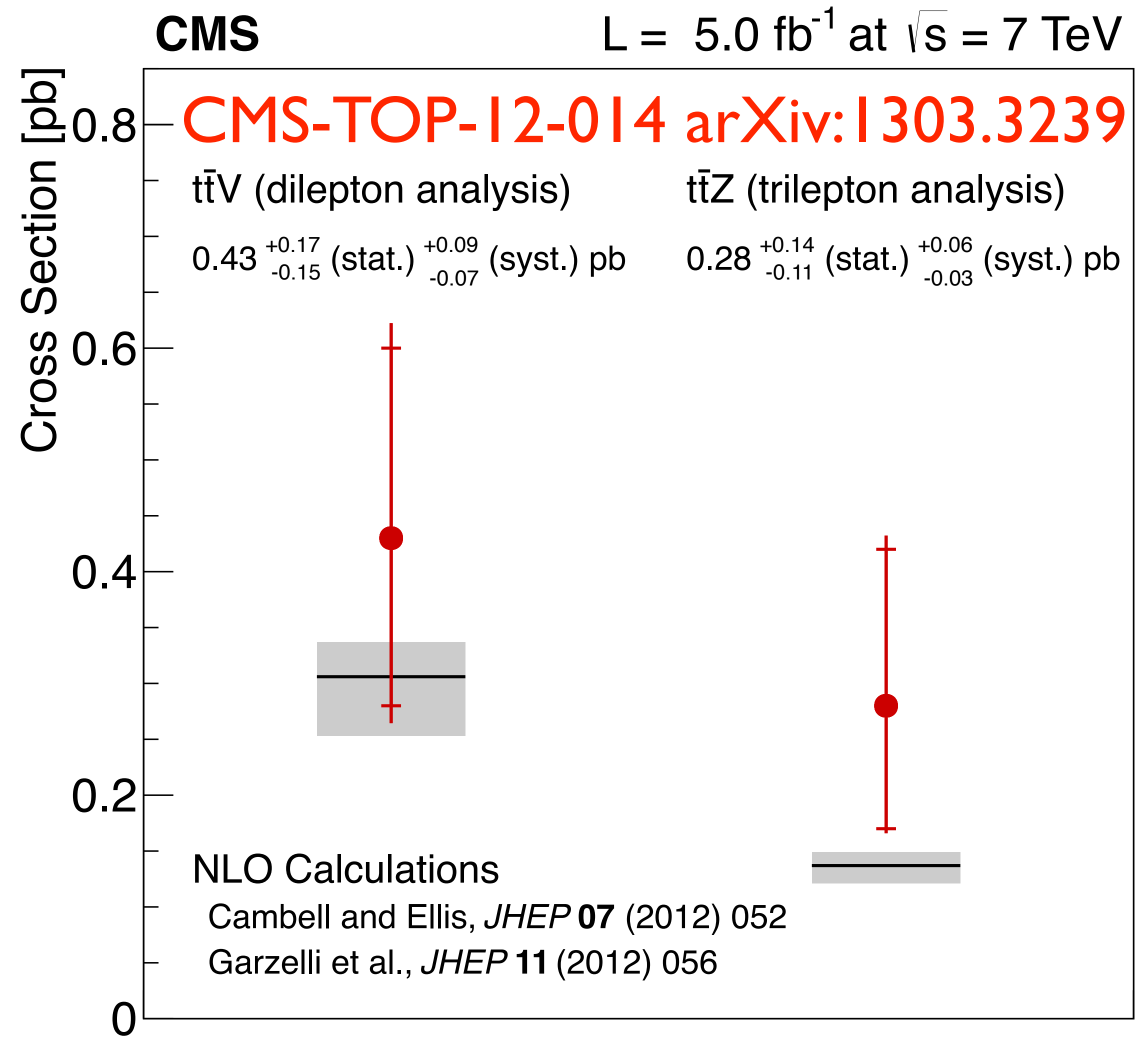
$t\bar{t}V$ at the LHC

- Cross-section measurements of $t\bar{t}V$ have been published by CMS for 7TeV
- More data expected to come from the 8TeV and the next 13TeV run



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- Prefers coupling to light quarks
- Has a fairly large asymmetry already at the LO (-4%)
- NLO QCD corrections slightly reduce the asymmetry
- Asymmetry is a mixed QED-QCD effect
- For a recent LO-based study, see arXiv:1402.3598
- σ_{NLO}=1.2pb at 13TeV (Frixione isolation, R=0.7 p_T>20 GeV, $|\eta|<2$)

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- It *only* couples to light quarks, no gg up to NNLO
- Has a fairly large asymmetry at the NLO (2-3%)
- It polarises the initial quark line, with some (very nice) surprises
- σ_{NLO}=0.55pb at 13TeV

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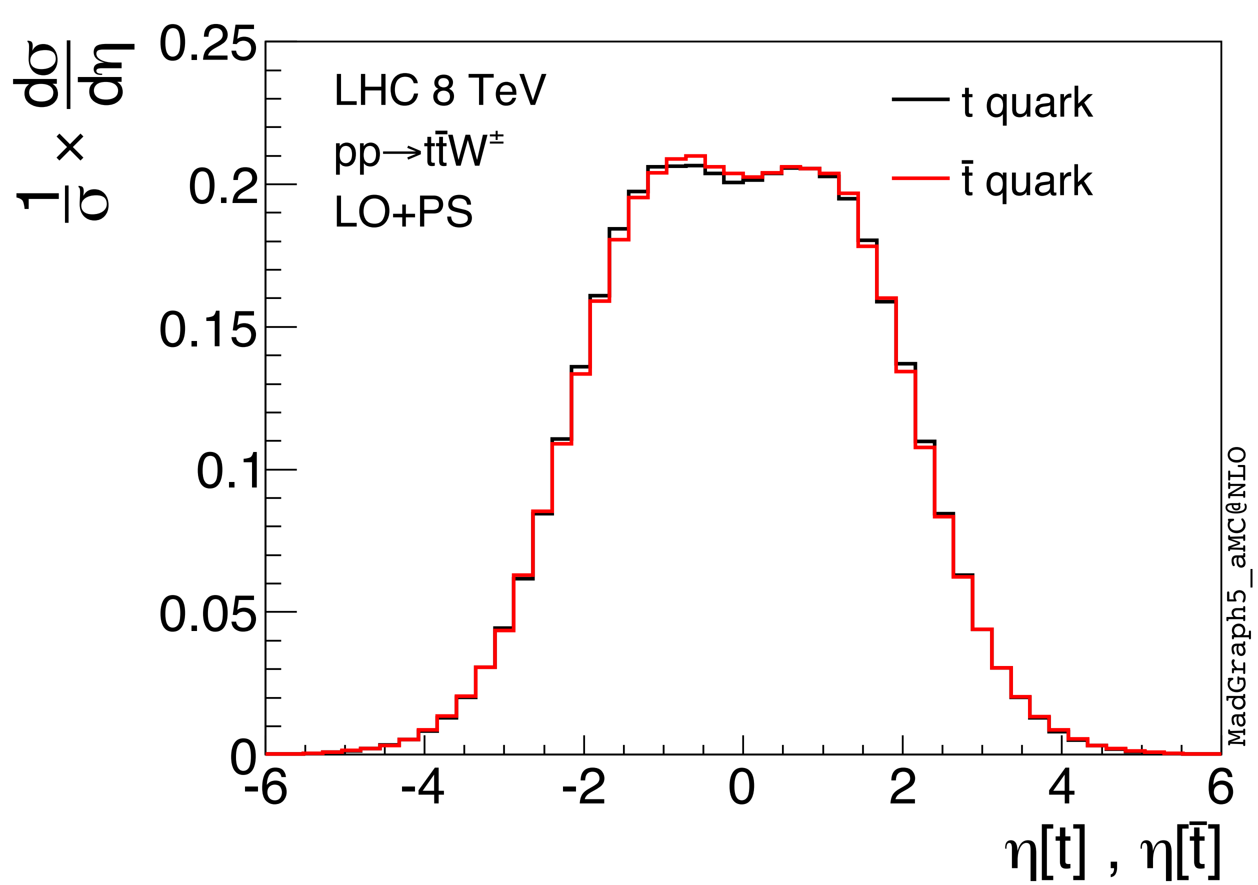

8TeV

$t\bar{t}$	LO	LO+PS	NLO	NLO+PS
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A_C^t (%)	0.01 ± 0.04	0.07 ± 0.03	$0.61^{+0.1}_{-0.08}$	$0.72^{+0.14}_{-0.09}$

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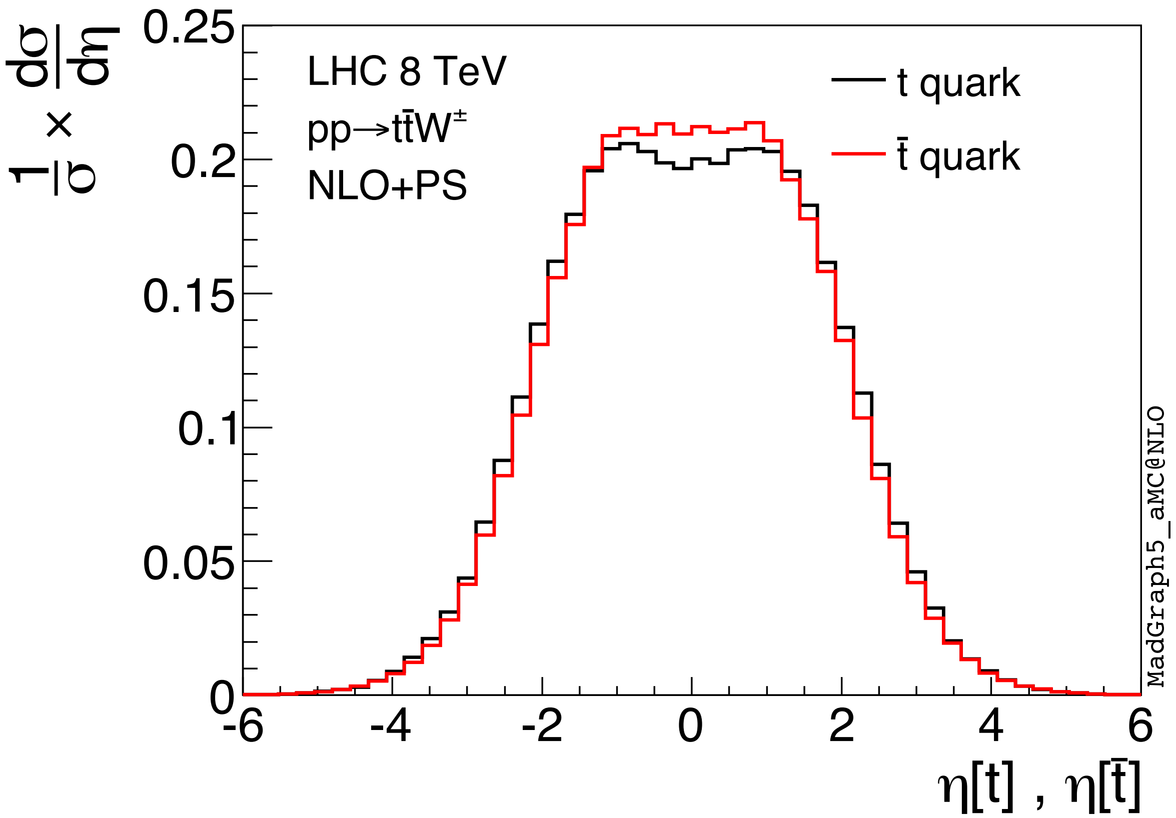

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Polarised top pair production

more in Parke, Shadmi, hep-ph:9606419

- Initial quarks are polarised by the W boson
  - $q\bar{q} \rightarrow t\bar{t}W$ is totally analogous to $q_L\bar{q}_R \rightarrow t\bar{t}$

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Possible top polarisation states in $q_L\bar{q}_R\to t\bar{t}$ (beam axis basis):

	$\beta\to 0$ (Thresh.)	$\beta\to 1$ (H.E.)
$\frac{d\sigma_{\uparrow\uparrow}}{d\cos\theta}=\frac{d\sigma_{\downarrow\downarrow}}{d\cos\theta}=\mathcal{N}(\beta)\frac{\beta^2(1-\beta^2)\sin^2\theta}{(1+\beta\cos\theta)^2}$	0	0
$\frac{d\sigma_{\downarrow\uparrow}}{d\cos\theta}=\mathcal{N}(\beta)\frac{\beta^4\sin^4\theta}{(1+\beta\cos\theta)^2}$	0	$\mathcal{N}(1)(1-\cos\theta)^2$
$\frac{d\sigma_{\uparrow\downarrow}}{d\cos\theta}=\mathcal{N}(\beta)\frac{[(1+\beta\cos\theta)^2+(1-\beta^2)]^2}{(1+\beta\cos\theta)^2}$	$4\mathcal{N}(0)$	$\mathcal{N}(1)(1+\cos\theta)^2$

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$\dfrac{d\sigma_{\uparrow\downarrow}}{d\cos\theta} = \mathcal{N}(\beta)\dfrac{[(1+\beta\cos\theta)^2+(1-\beta^2)]^2}{(1+\beta\cos\theta)^2}$	$4\mathcal{N}(0)$	$\mathcal{N}(1)(1+\cos\theta)^2$

- At threshold (leading contribution to the cross-section) only one polarisation survives: tops are fully polarised
- At high energies top polarisations are opposite, and #↑↓=#↓↑

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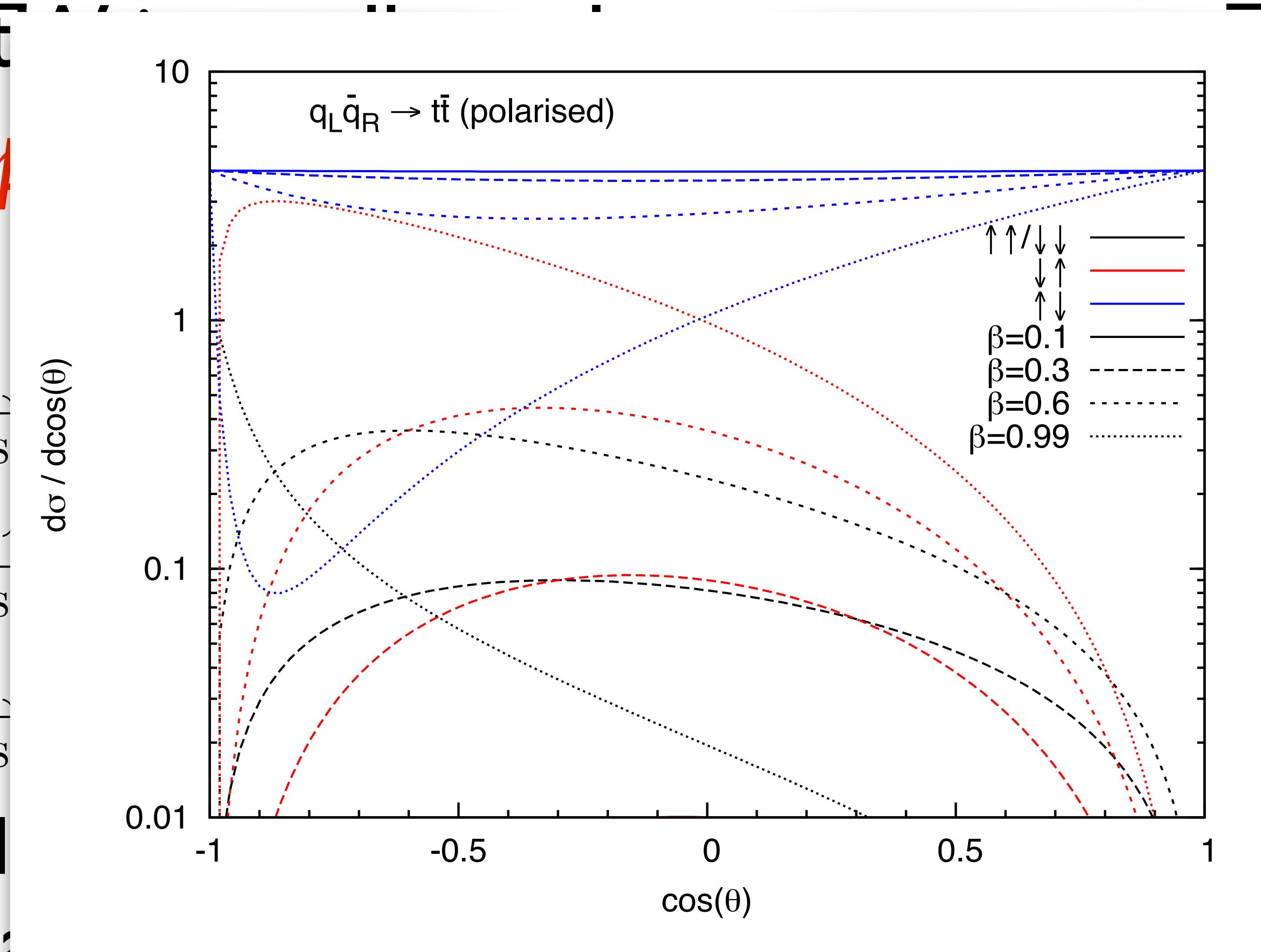
Possible top p ... axis basis):



$\beta \to 1$

(H.E.)

$$\frac{d\sigma_{\uparrow\uparrow}}{d\cos\theta} = \frac{d\sigma_{\downarrow}}{d\cos} \quad \ldots$$

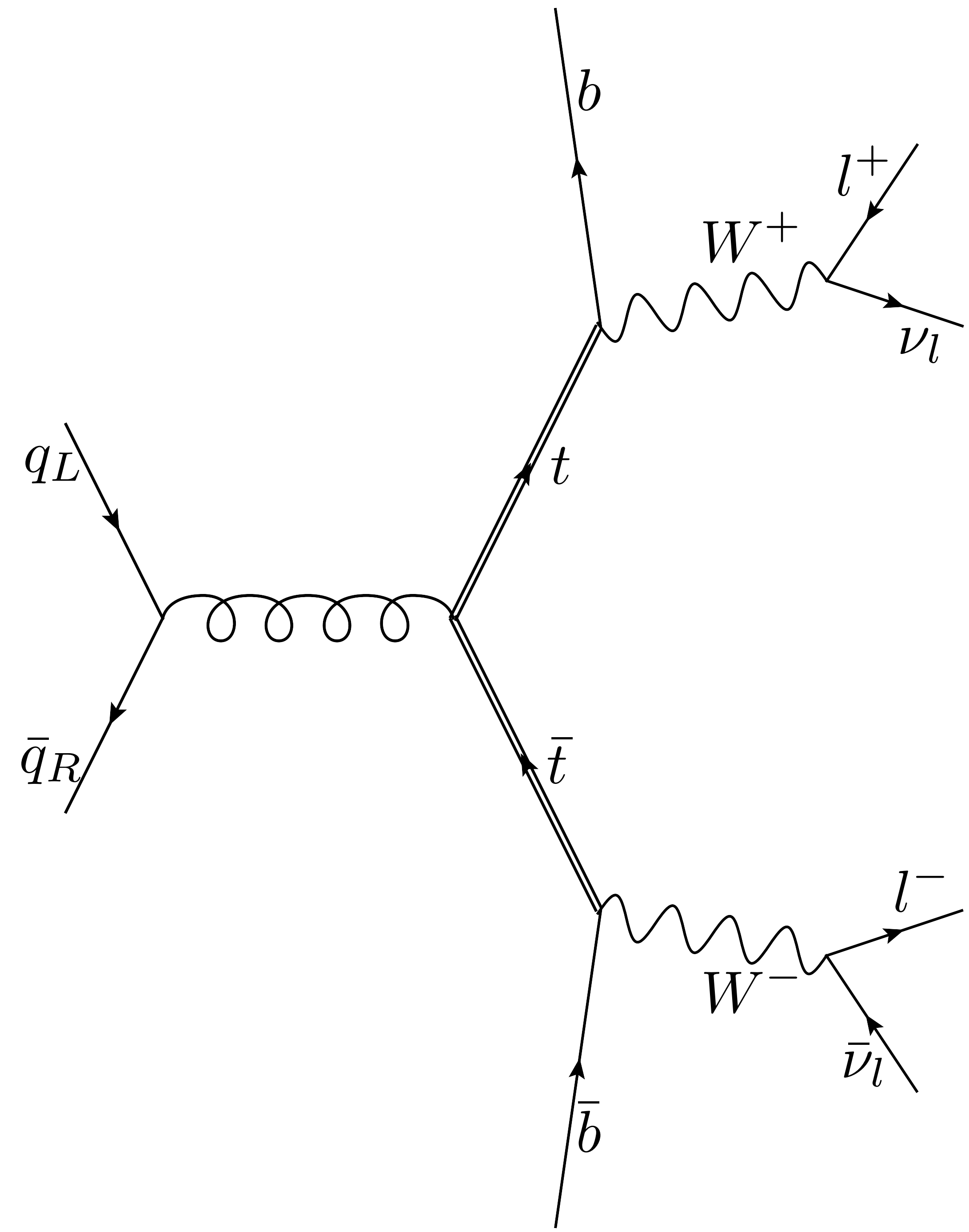
$$\frac{d\sigma_{\downarrow}}{d\cos} \quad \ldots)(1-\cos\theta)^2$$

$$\frac{d\sigma_{\uparrow}}{d\cos} \quad \ldots)(1+\cos\theta)^2$$

- At threshol ... ection) only one polaris...
- At high energies top polarisations are opposite, and #↑↓=#↓↑

Polarisation effects

- The produced tops are highly polarised, leading to asymmetric decay products already at LO
  - Leptons from tops are strongly correlated with top polarisation
  - Need to include spin-correlations to see this effect
  - Decay products asymmetries are much larger than the top one



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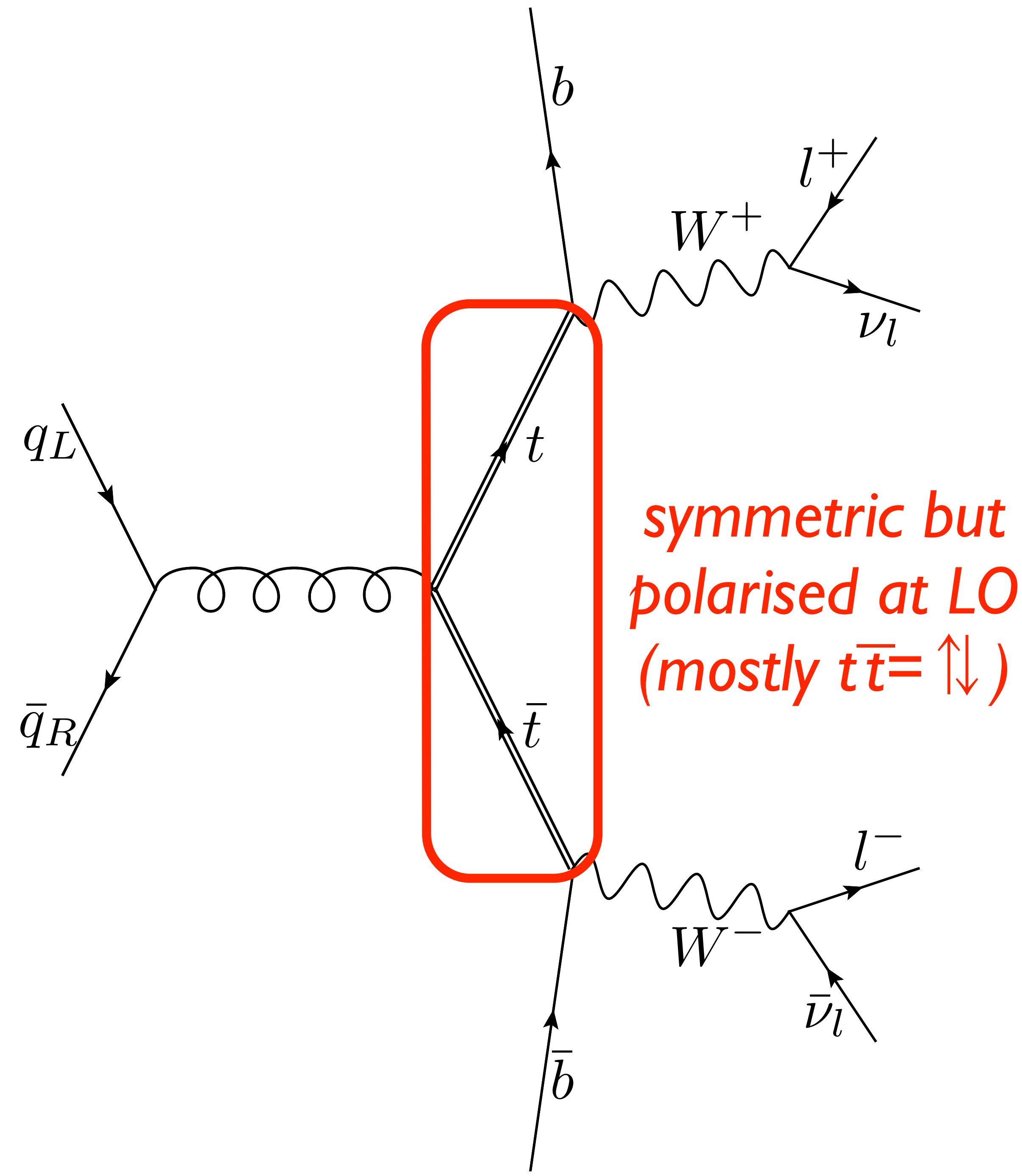

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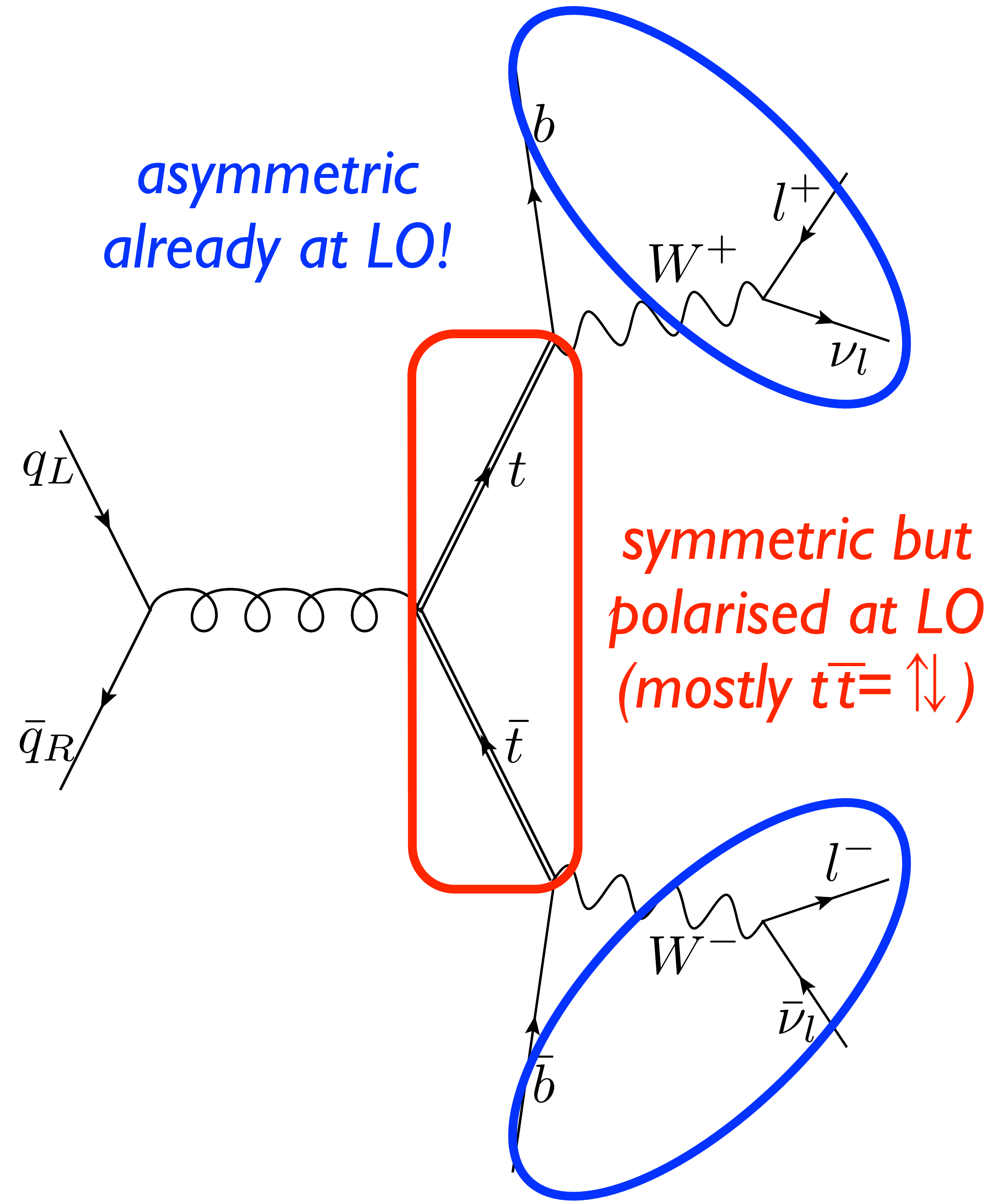
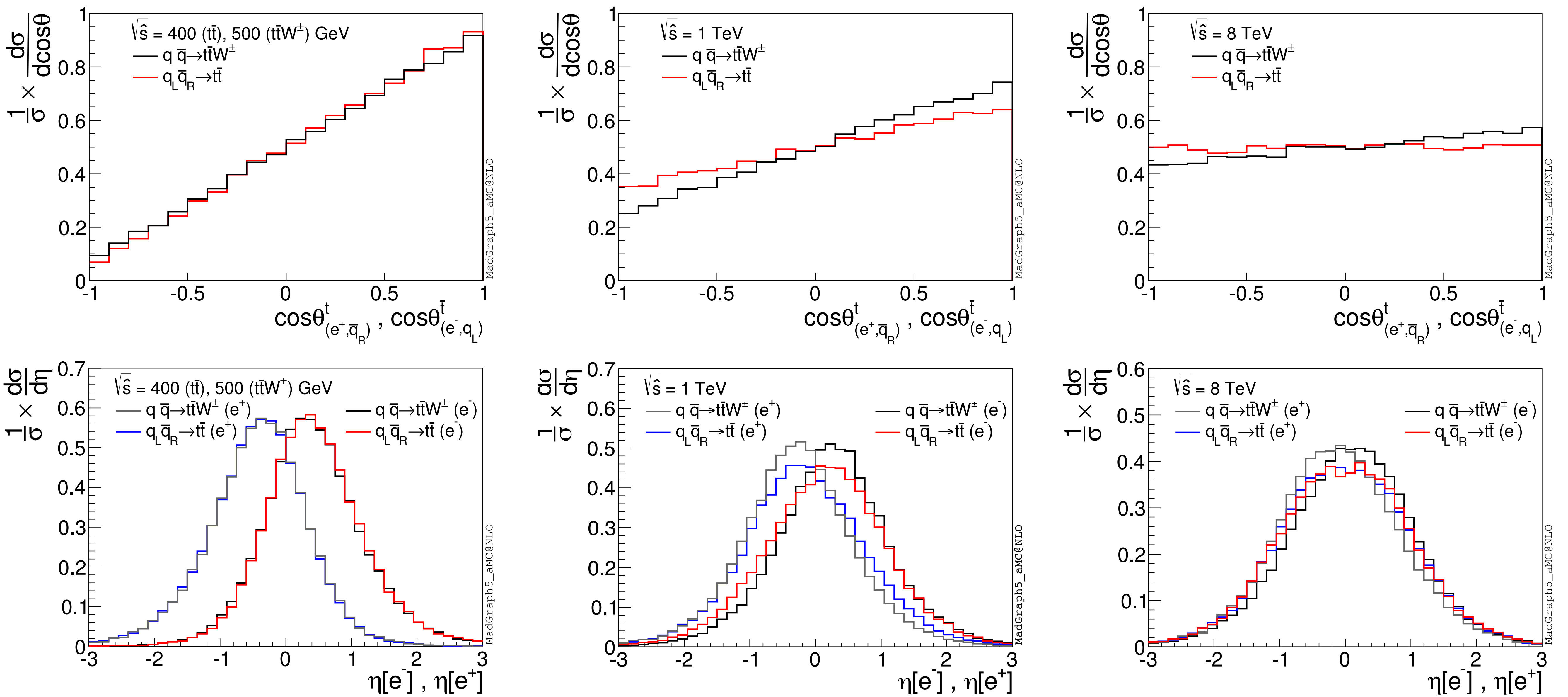


Polarisation effects

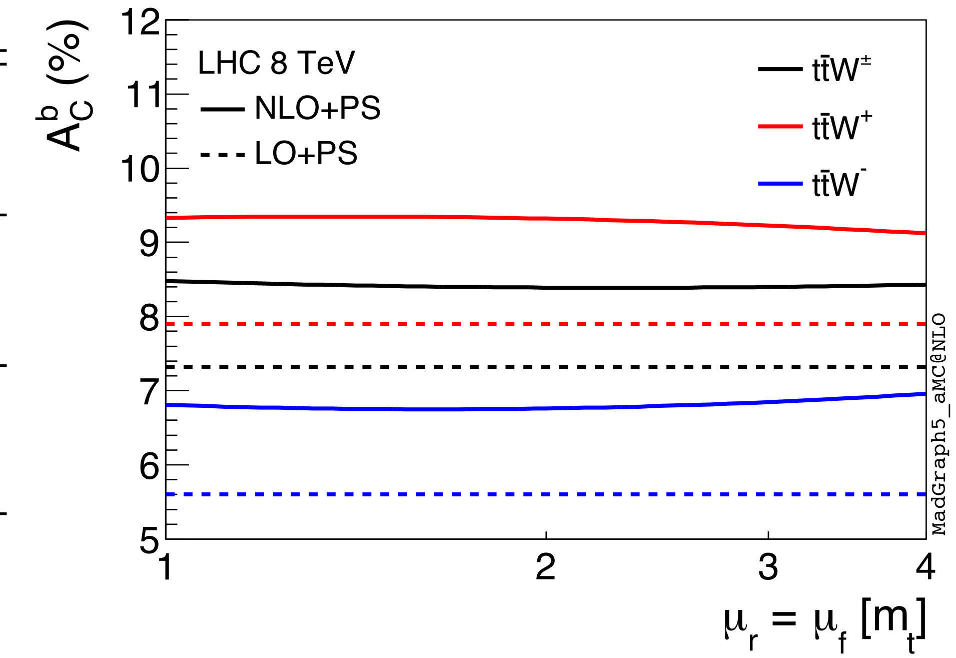
Threshold *Intermediate* *High Energy*

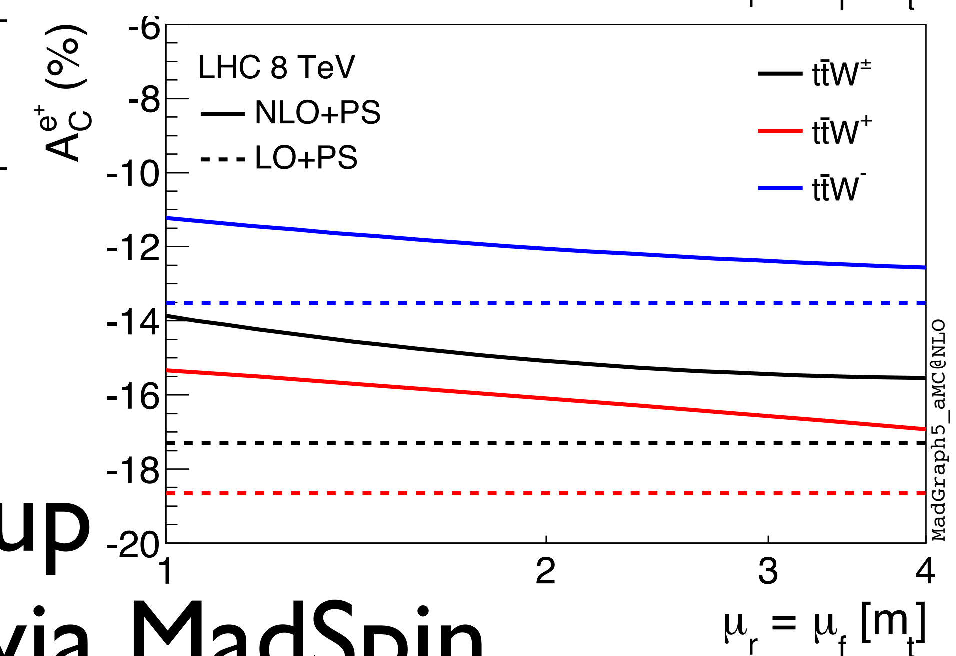


Polarisation effects: results

	Order	$t\bar{t}W^{\pm}$	$t\bar{t}W^{+}$	$t\bar{t}W^{-}$
$^*A_C^b$ (%)	LO+PS	$7.32^{+0.08}_{-0.28}$	$7.90^{+0.14}_{-0.16}$	$5.60^{+0.14}_{-0.08}$
	NLO+PS	$8.39^{+0.09}_{+0.04}$	$9.32^{+0.01}_{-0.20}$	$6.76^{+0.05}_{-0.11}$
A_C^e (%)	LO+PS	$-17.30^{-0.07}_{+0.27}$	$-18.65^{-0.18}_{+0.07}$	$-13.51^{-0.02}_{+0.05}$
	NLO+PS	$-15.1^{-1.2}_{+0.4}$	$-16.1^{-0.8}_{+0.8}$	$-12.1^{-0.9}_{+0.5}$

***b-jets, k_T-algo, R=0.5, p_T>20 GeV, |y|<4.5, MCTruth**





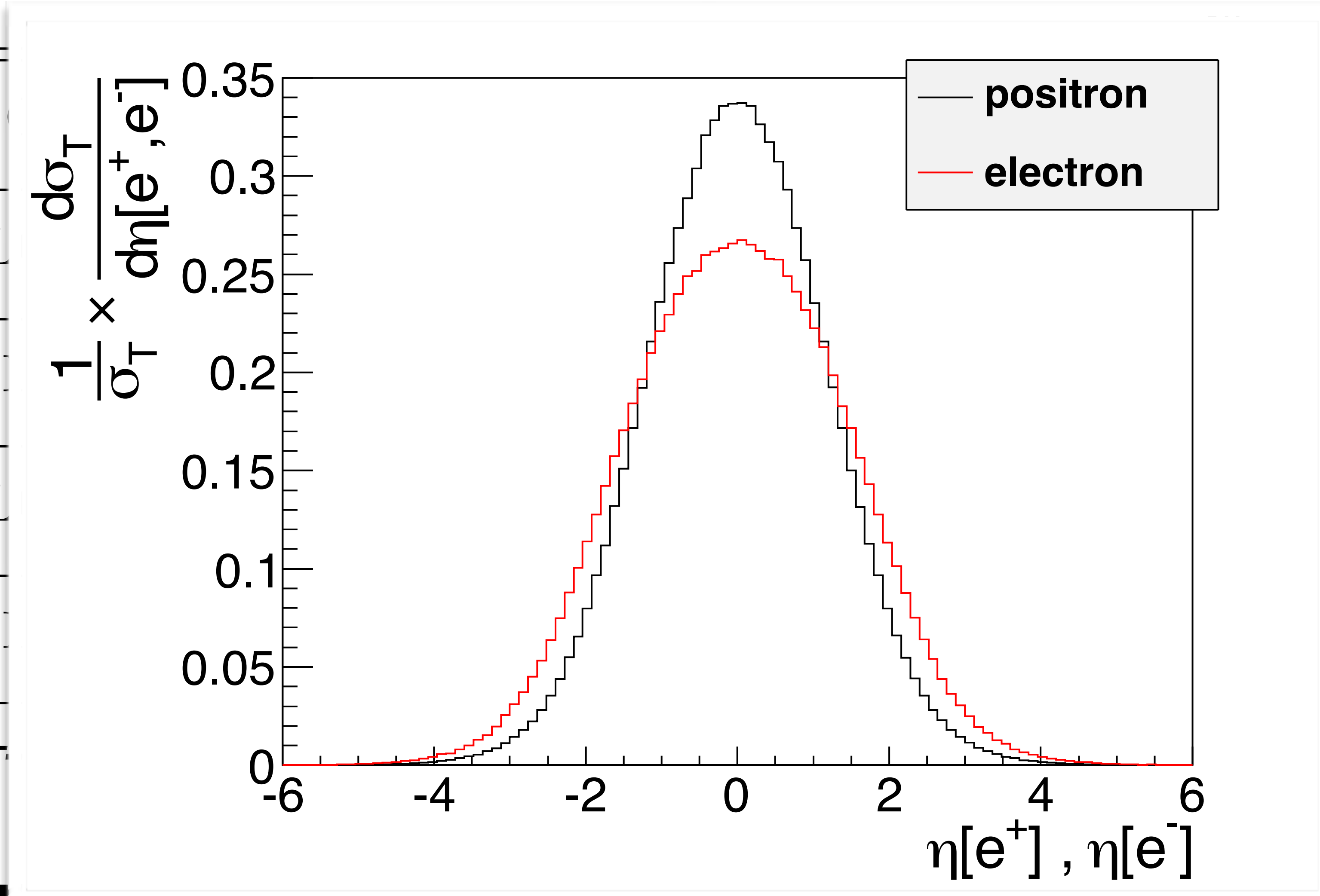
- Asymmetries are large!
- NLO corrections shift all numbers up
- Spin correlations included at NLO via MadSpin

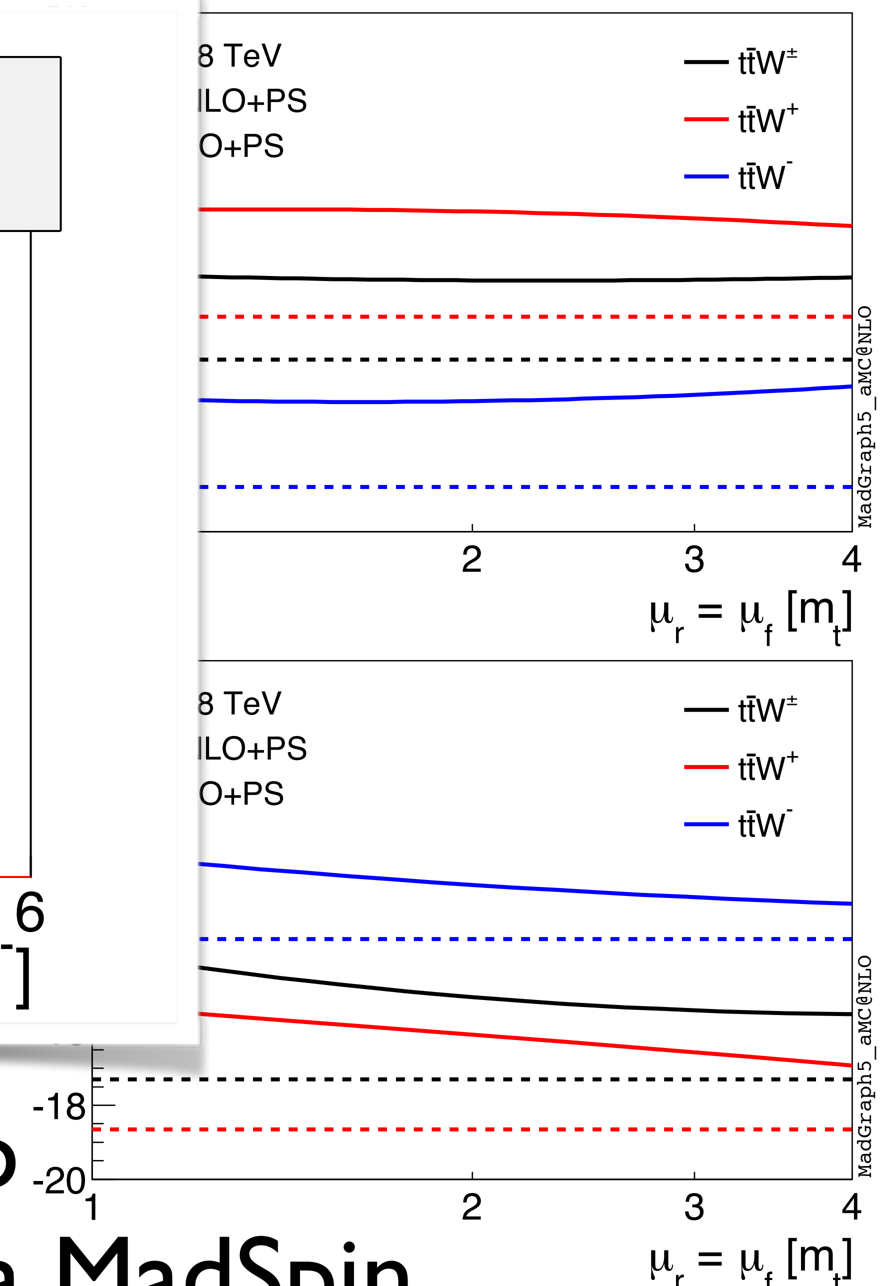
Artoisenet, Frederix, Mattelaer, Rietkerk, arXiv:1212.3460

Polarisation effects: results

*A_C^b (%)	L
	N
A_C^e (%)	L
	N

*b-jets, k_T





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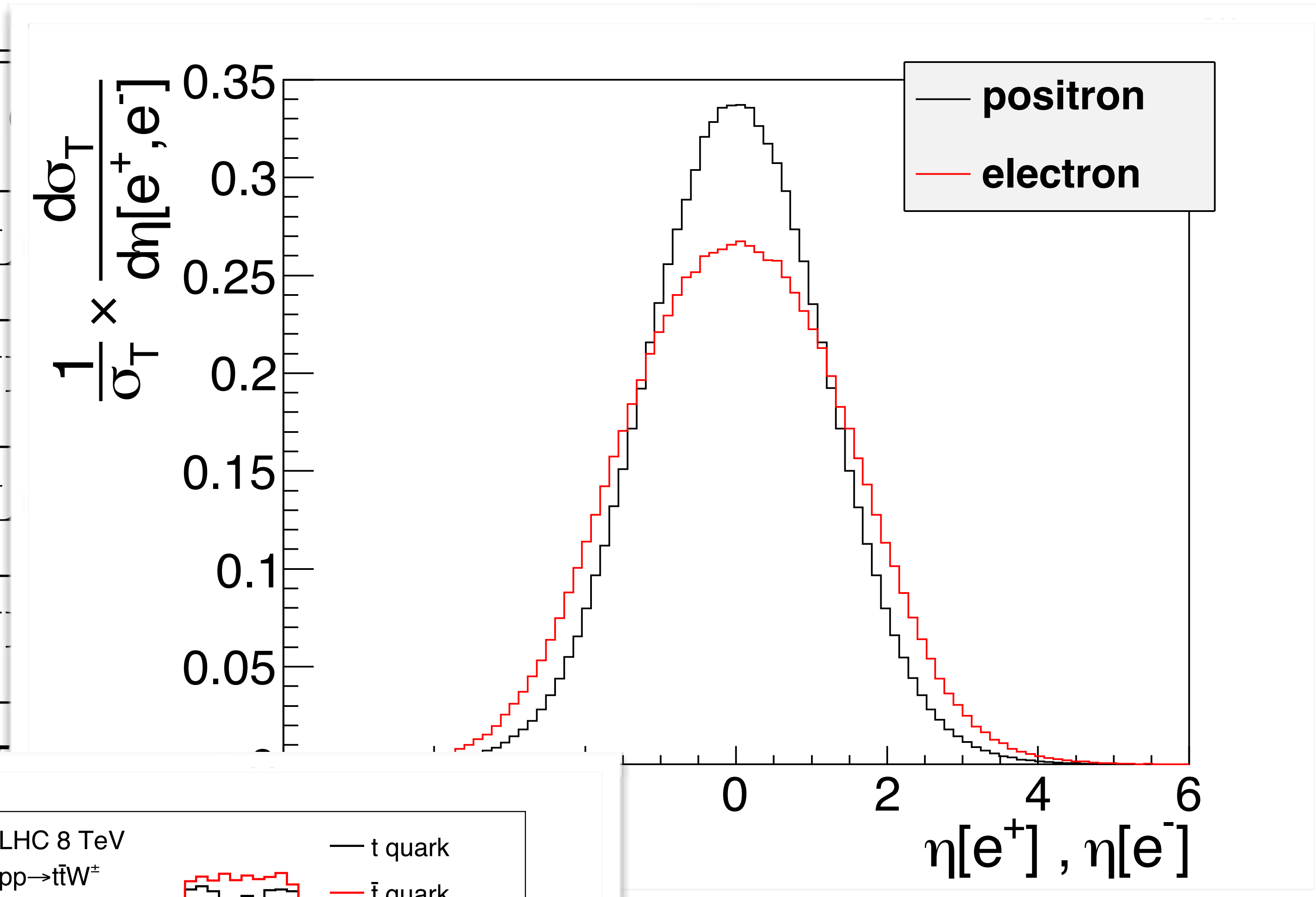
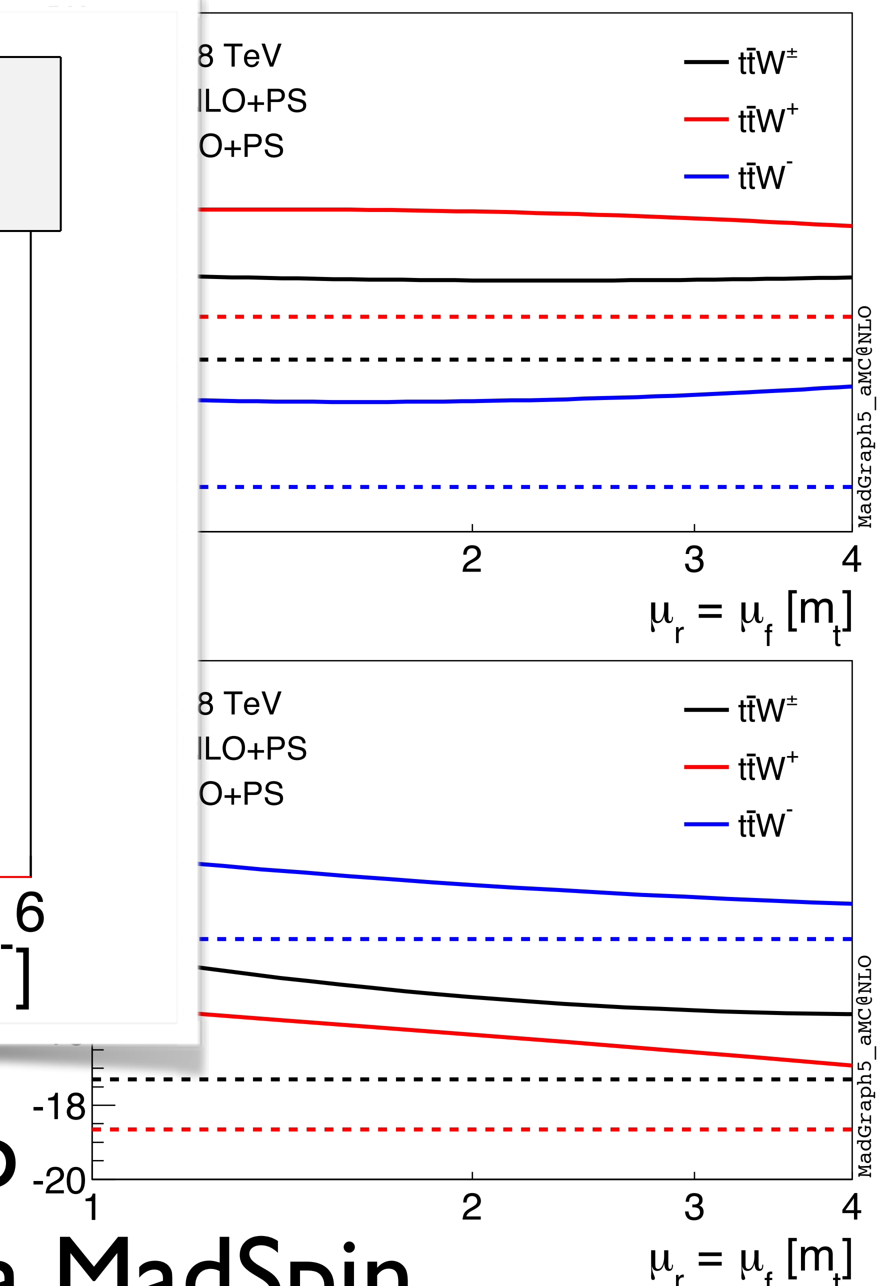
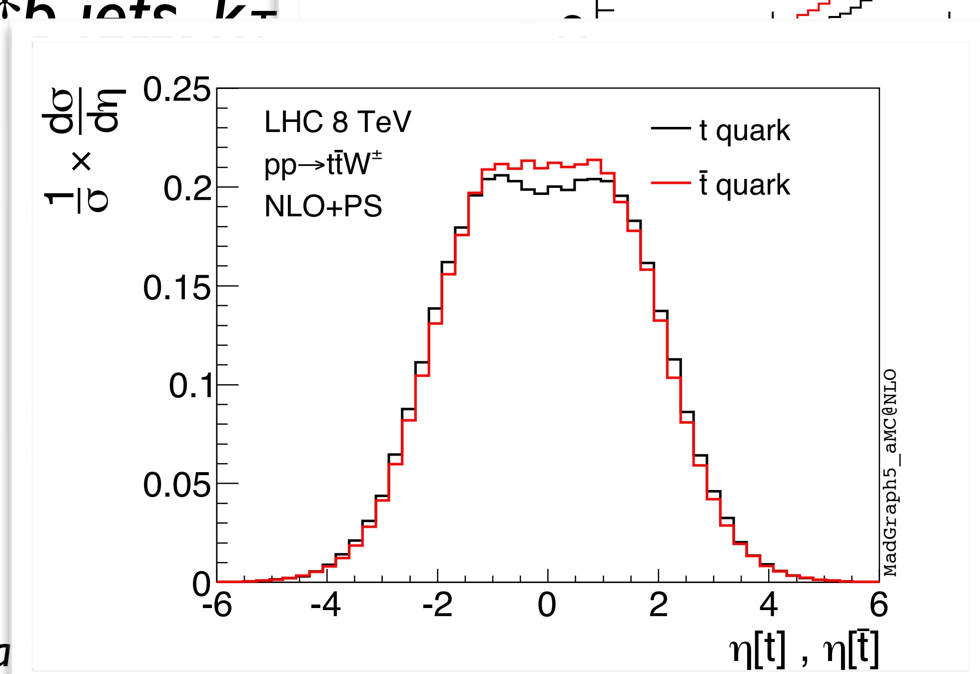
$^*A_C^b$ (%)	L	
	N	
A_C^e (%)	L	
	N	

*b jets, k_T







-
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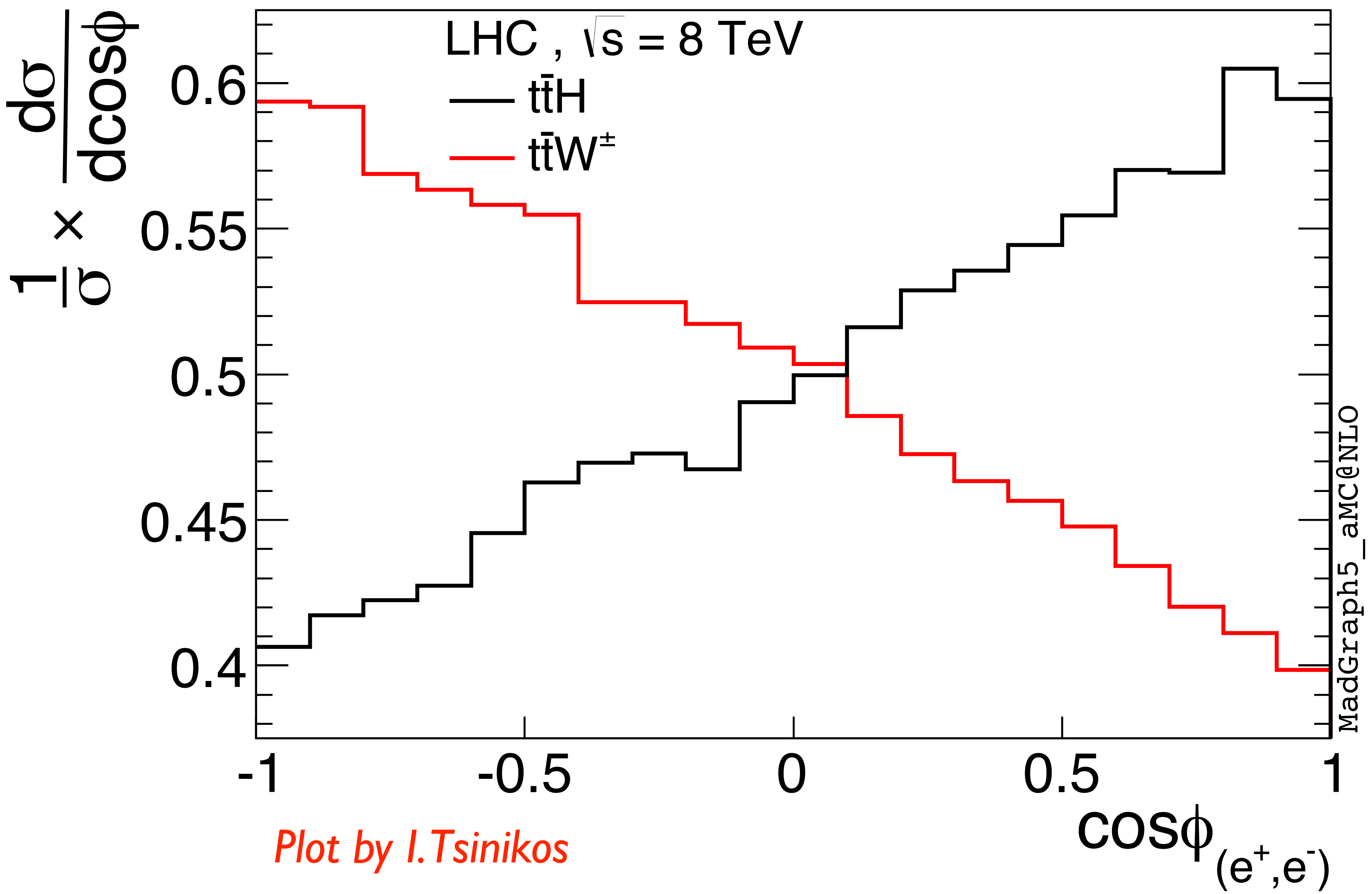
Polarisation effects: $t\bar{t}W$ vs $t\bar{t}H$



Plot by I.Tsinikos

Plans for the future…

		8 TeV	13 TeV	14 TeV	33 TeV	100 TeV
$t\bar{t}$	σ(pb)	$198^{+15\%+2\%}_{-14\%-3\%}$	$661^{+15\%+2\%}_{-13\%-3\%}$	$786^{+14\%+2\%}_{-13\%-3\%}$	$4643^{+12\%+1\%}_{-11\%-2\%}$	$30670^{+13\%+1\%}_{-13\%-2\%}$
	$A_C^t(\%)$	$0.72^{+0.14}_{-0.09}$	$0.45^{+0.09}_{-0.06}$	$0.36^{-0.01}_{-0.02}$	$0.11^{+0.07}_{+0.04}$	$0.07^{+0.02}_{-0.04}$
$t\bar{t}W^{\pm}$	σ(fb)	$210^{+11\%+2\%}_{-11\%-2\%}$	$587^{+13\%+2\%}_{-12\%-1\%}$	$678^{+14\%+2\%}_{-12\%-1\%}$	$3216^{+17\%+1\%}_{-13\%-1\%}$	$18970^{+20\%+1\%}_{-17\%-1\%}$
	$A_C^t(\%)$	$2.3^{+0.6}_{-0.40}$	$2.24^{+0.56}_{-0.28}$	$2.23^{+0.29}_{-0.19}$	$2.01^{+0.02}_{-0.27}$	$1.84^{-0.24}_{-0.08}$
	$A_C^b(\%)$	$8.50^{+0.15}_{-0.10}$	$7.56^{+0.09}_{-0.03}$	$7.56^{+0.16}_{-0.10}$	$5.51^{+0.26}_{-0.17}$	$3.60^{-0.53}_{-0.16}$
	$A_C^e(\%)$	$-14.83^{-0.65}_{+0.95}$	$-13.11^{-1.20}_{+0.95}$	$-12.82^{-1.07}_{+0.86}$	$-9.26^{-1.09}_{+0.79}$	$-4.84^{-0.47}_{+0.84}$

A look BSM

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- Several BSM solutions have been proposed to cure the discrepancies observed at the Tevatron
- What is their effect at the LHC, in particular for $t\bar{t}W$?

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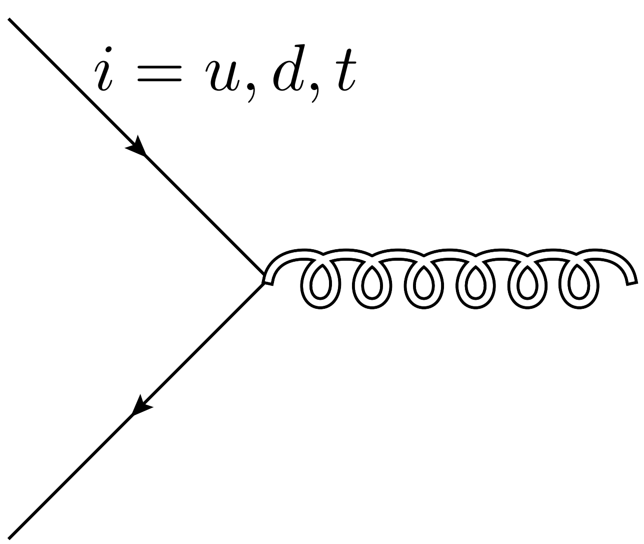
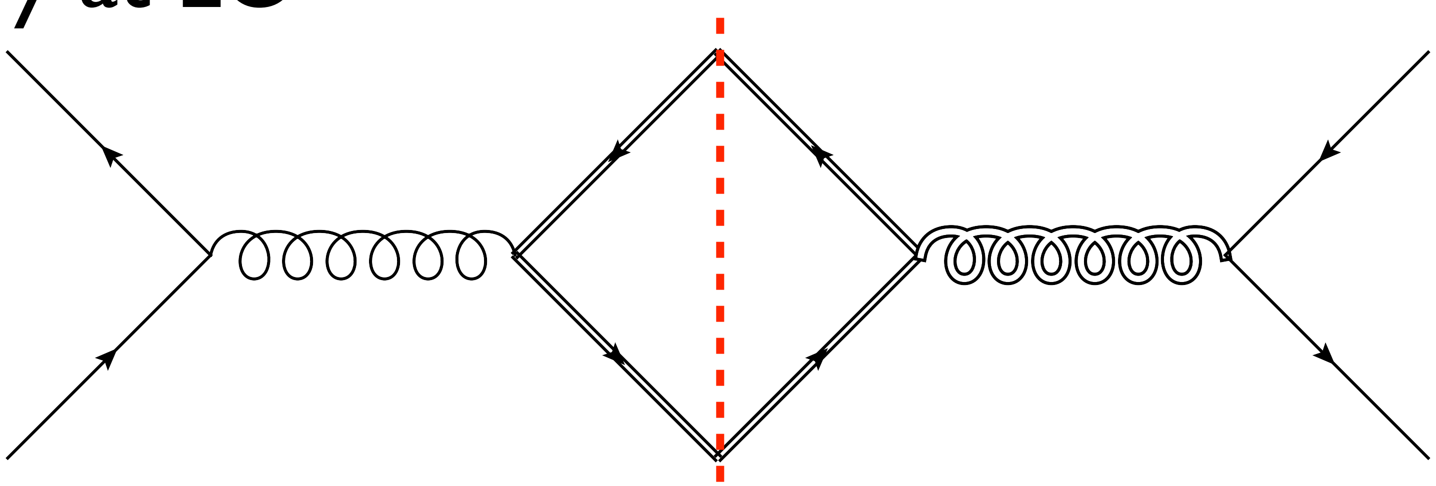
  - Extra color octet G which couples differently to quarks of different chiralities and to u/d and heavy quarks



$$= \quad \lambda^a \left(\frac{1-\gamma_5}{2} g_L^i + \frac{1+\gamma_5}{2} g_R^i \right) \gamma^\mu$$

A look BSM

- Several BSM solutions have been proposed to cure the discrepancies observed at the Tevatron
- What is their effect at the LHC, in particular for $t\bar{t}W$?
- Choose one simple case: the axigluon model *Frampton, Shu, Wang arXiv:0911.2955*
  - Extra color octet G which couples differently to quarks of different chiralities and to u/d and heavy quarks
  - The interference between the gluon and axigluon gives an asymmetry at LO

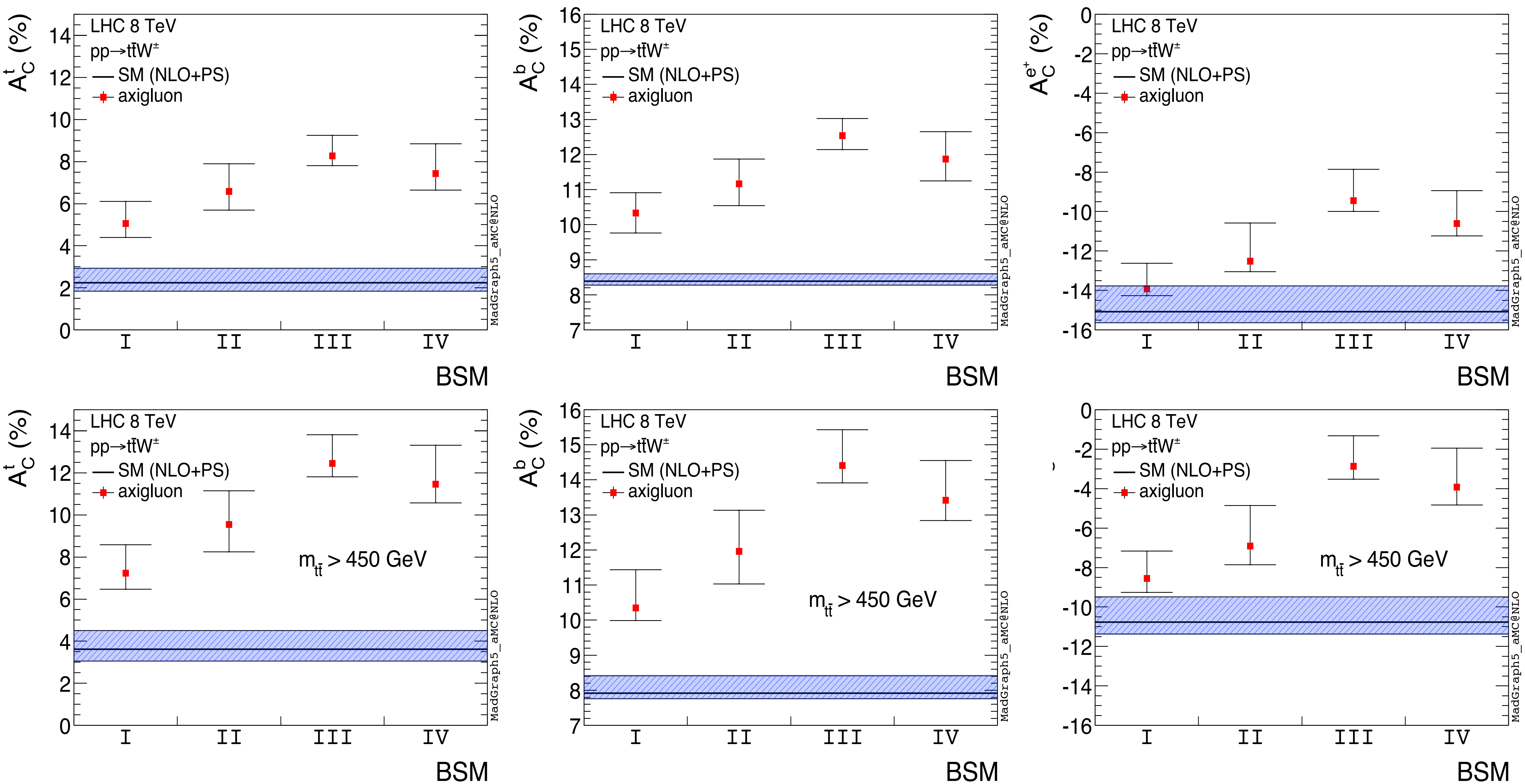


Benchmark scenarios:

Light, universal G		Heavy, non-universal G	
I (left)	II (axial)	III (left)	IV (axial)
m		m	
Γ_G		Γ	Γ
g	g	g	g
g	g	g	g^u
g_t		g	g

W boson polarises light quarks: σ=0 in right-handed scenarios

Results


LHC 8 TeV
pp→tt̄W±
SM (NLO+PS)
axigluon
A_C^t (%)
A_C^b (%)
$A_C^{e^+}$ (%)
$m_{t\bar{t}} > 450$ GeV
I
II
III
IV
BSM
MadGraph5_aMC@NLO

Conclusions

- The top quark asymmetry is a very intriguing observable which can provide us with some hints on new physics
- Measurement at the LHC is very tricky
  - symmetric initial state
  - large gg fraction
- The associated production of a top pair and a W boson is a very interesting channel to look at
  - Larger asymmetry than $t\bar{t}$
  - Tops are highly polarised $\rightarrow$ asymmetric decay products at LO
  - Together with $t\bar{t}$, $t\bar{t}W$ can provide useful informations on NP

Thanks for your attention!