

Adam Falkowski (LPT Orsay)

Top Asymmetry



at



Hadron Colliders

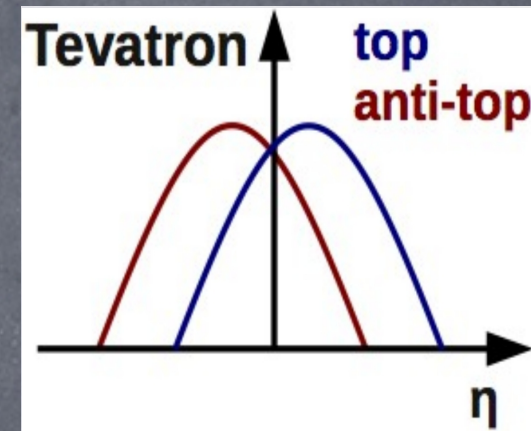
Workshop on Top physics at the LC

Jussieu, 5 March 2014

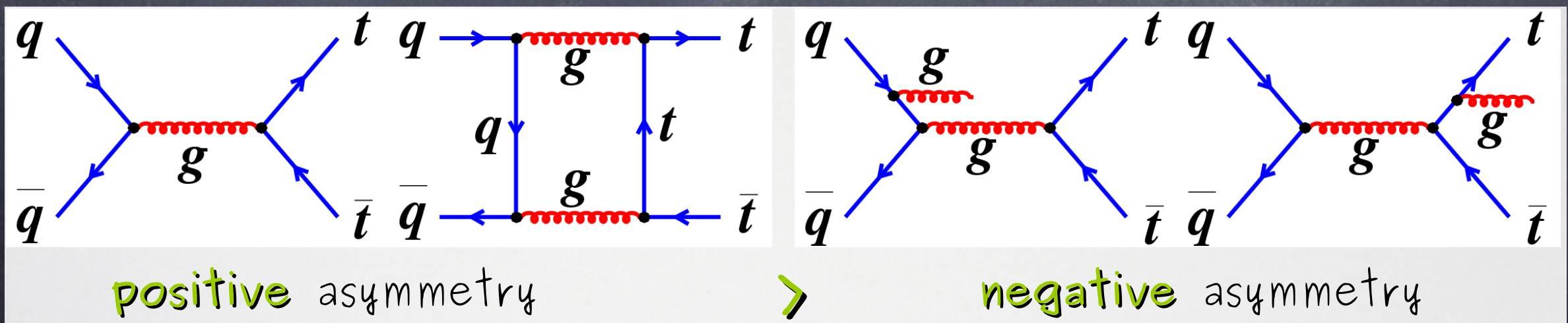
Top FB Asymmetry @ Tevatron

Longitudinal
boost
independent; in
t-tbar rest frame
reduces to
forward-
backward top
asymmetry

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



- At zeroth order t-tbar production in QCD is FB symmetric, but an asymmetry may arise due higher order QCD corrections, and possibly new physics with chiral couplings to quarks



Experimental Status

Inclusive asymmetry, naive CDF/D0 combination

$$A_{t\bar{t}} = 0.174 \pm 0.038$$

Inclusive asymmetry @Tevatron, SM prediction

$$A_{t\bar{t}}^{\text{SM}} = 0.09 \pm 0.01$$

$\sim 2.5\sigma$ deviation from the SM

High $m_{t\bar{t}}$ asymmetry @CDF 9fb⁻¹,

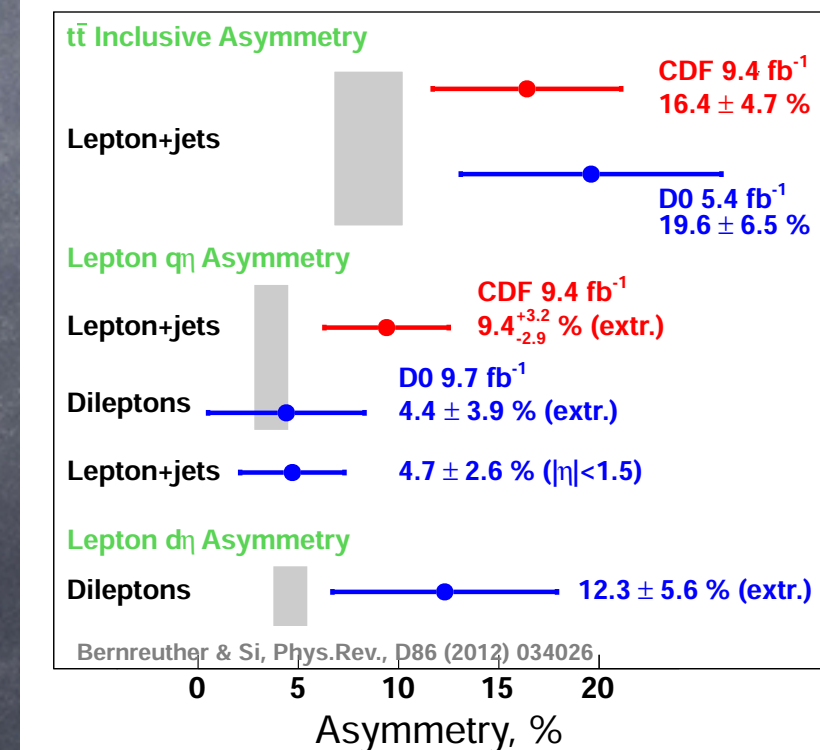
$$A_{t\bar{t}}(m_{t\bar{t}} > 450\text{GeV}) = 0.295 \pm 0.066$$

High $m_{t\bar{t}}$ asymmetry @ Tevatron, SM prediction

$$A_{t\bar{t}}^{\text{SM}}(m_{t\bar{t}} > 450\text{GeV}) = 0.13 \pm 0.01$$

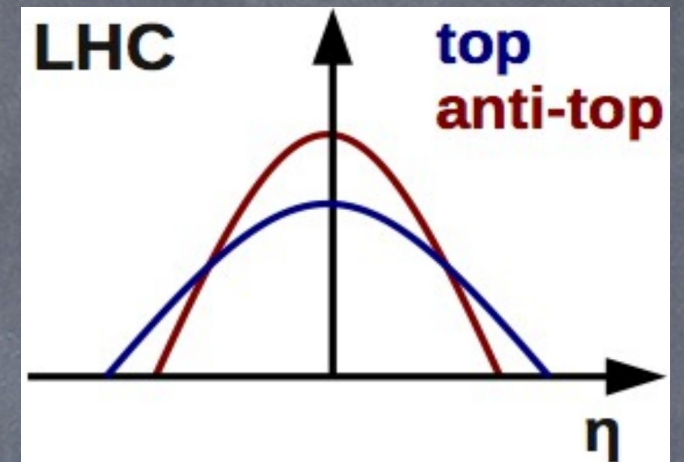
$\sim 2\sigma$ deviation from the SM

- Anomalous t - t bar forward-backward asymmetry at the Tevatron remains one of a few surviving hints of new physics
- Not enough to claim evidence for new physics, but enough to warrant further investigation



Top charge asymmetry @LHC

$$A_C^{t\bar{t}} = \frac{N(\Delta|y|^{t\bar{t}} > 0) - N(\Delta|y|^{t\bar{t}} < 0)}{N(\Delta|y|^{t\bar{t}} > 0) + N(\Delta|y|^{t\bar{t}} < 0)},$$



- FB asymmetry vanishes due to symmetric initial state
- But underlying FB asymmetry of quark-antiquark collisions can show up as different rapidity distribution of top and anti-top

Experimental Status

Semileptonic:

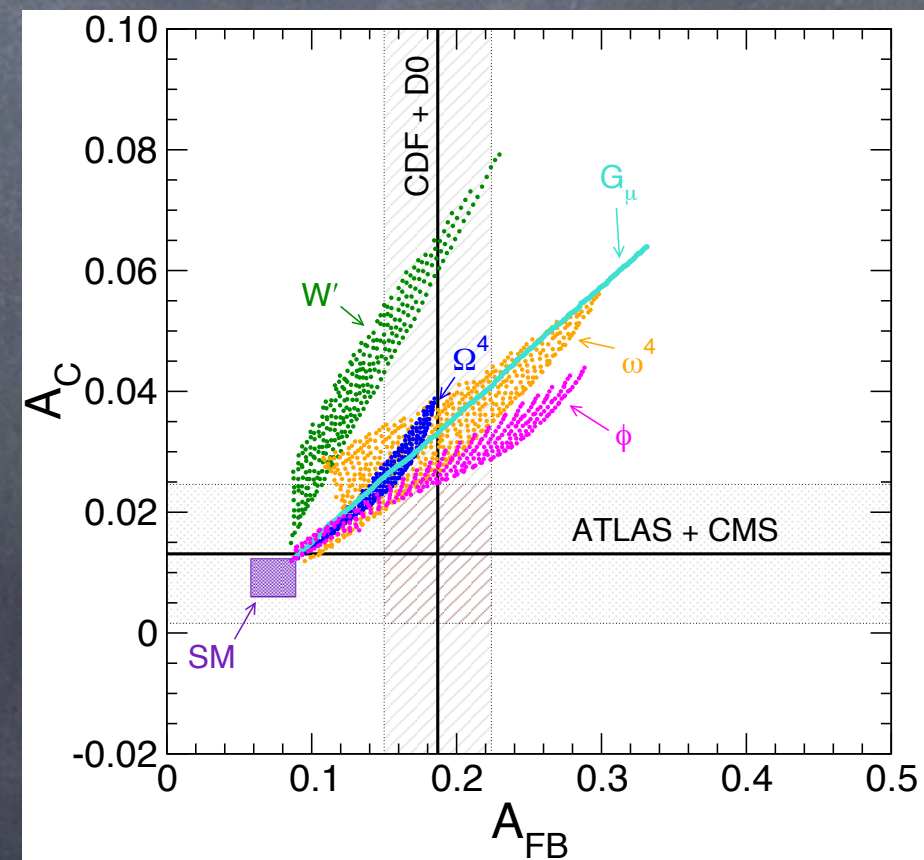
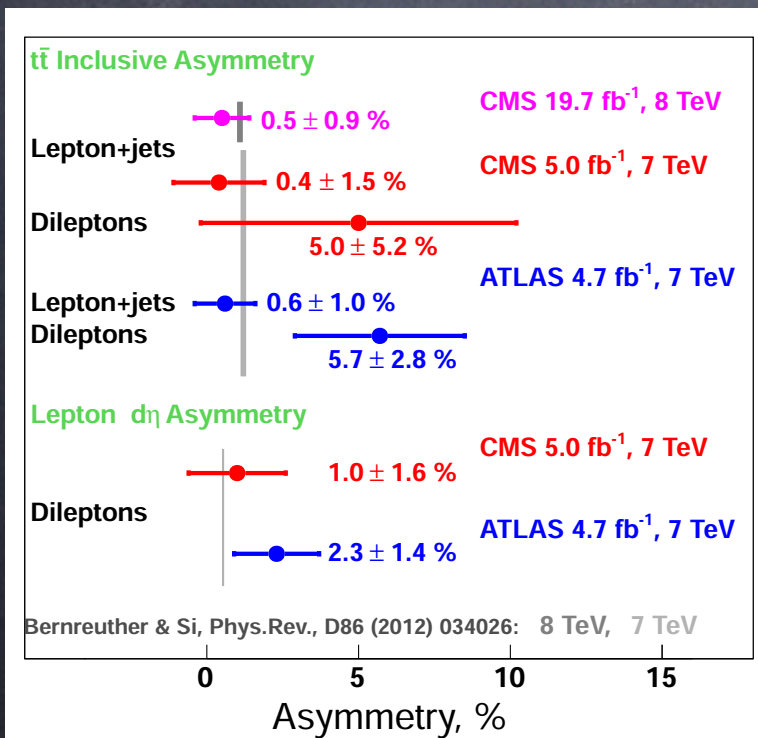
$$\begin{aligned} A_C^{t\bar{t}}(\text{ATLAS}, 7 \text{ TeV}) &= 0.006 \pm 0.010, \\ A_C^{t\bar{t}}(\text{CMS}, 7 \text{ TeV}) &= 0.004 \pm 0.010 \pm 0.011 \\ A_C^{t\bar{t}}(\text{CMS}, 8 \text{ TeV}) &= 0.005 \pm 0.007 \pm 0.006, \end{aligned}$$

Dileptonic:

$$\begin{aligned} A_C^{t\bar{t}}(\text{ATLAS}, 7 \text{ TeV}) &= 0.057 \pm 0.024 \pm 0.015, \\ A_C^{t\bar{t}}(\text{CMS}, 7 \text{ TeV}) &= 0.050 \pm 0.043^{+0.010}_{-0.039}, \end{aligned}$$

with the SM prediction around 0.01

- No hint of an excess... but still some room for new physics



from Aguilar-Saavedra, Perez-Victoria 1302.6618

Lepton-based FB Asymmetries

Tevatron

$$A_\ell = \frac{N(q \times \eta > 0) - N(q \times \eta < 0)}{N(q \times \eta > 0) + N(q \times \eta < 0)},$$

$$A_{\ell\ell} = \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)},$$

Frame-dependent,
here in the LAB frame

Longitudinal boost independent; in
t-tbar rest frame reduces to
forward-backward top asymmetry

LHC

$$A_C^{\ell\ell} = \frac{N(\Delta|\eta|^{l^+l^-} > 0) - N(\Delta|\eta|^{l^+l^-} < 0)}{N(\Delta|\eta|^{l^+l^-} > 0) + N(\Delta|\eta|^{l^+l^-} < 0)},$$

$$A_C^{t\ell} = \frac{N(\Delta|y|^{t\ell} > 0) - N(\Delta|y|^{t\ell} < 0)}{N(\Delta|y|^{t\ell} > 0) + N(\Delta|y|^{t\ell} < 0)},$$

dileptonic

semileptonic

- Lepton based asymmetries in t-tbar events are in principle independent observables that can reveal or constrain new physics

Experimental Status

Tevatron

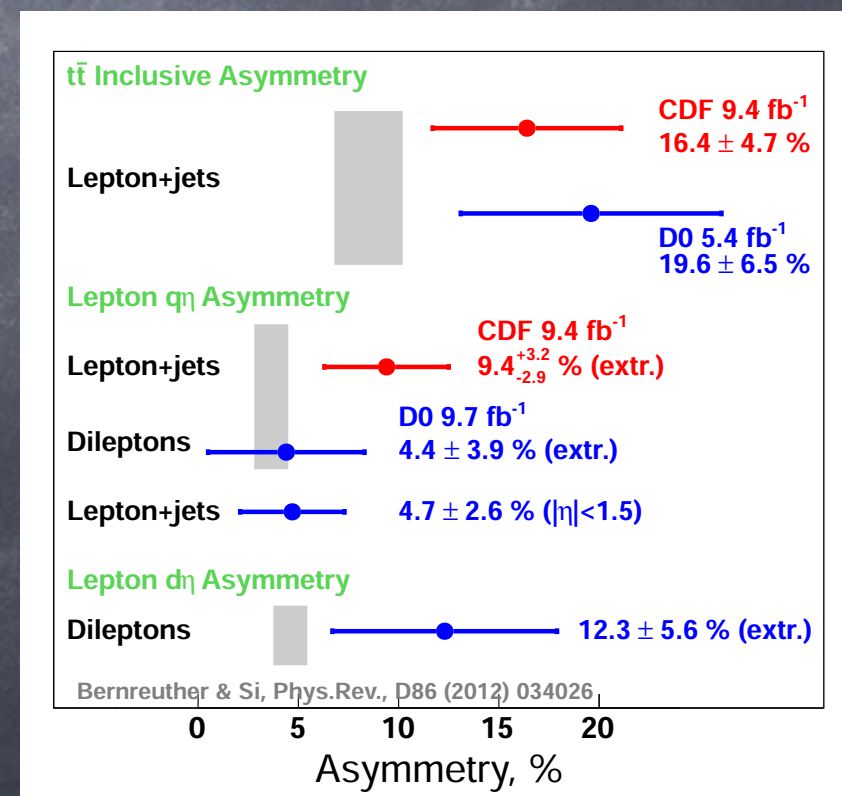
$$\begin{aligned}
 \text{SL : } A_\ell(\text{CDF}) &= 0.094 \pm 0.024^{+0.022}_{-0.017}, \\
 \text{SL : } A_\ell(\text{D}\emptyset) &= 0.047 \pm 0.023^{+0.011}_{-0.014}, \\
 \text{DL : } A_\ell(\text{CDF}) &= 0.072 \pm 0.052 \pm 0.030, \\
 \text{DL : } A_\ell(\text{D}\emptyset) &= 0.044 \pm 0.037 \pm 0.011, \\
 \text{DL : } A_{\ell\ell}(\text{CDF}) &= 0.076 \pm 0.072 \pm 0.037, \\
 \text{DL : } A_{\ell\ell}(\text{D}\emptyset) &= 0.123 \pm 0.054 \pm 0.015,
 \end{aligned}$$

$$\begin{aligned}
 A_\ell(\text{SM}) &= 0.038 \pm 0.003, \\
 A_\ell(\text{SM}) &= 0.023, \\
 A_\ell(\text{SM}) &= 0.038 \pm 0.003, \\
 A_\ell(\text{SM}) &= 0.024 \pm 0.001, \\
 A_{\ell\ell}(\text{SM}) &= 0.048 \pm 0.004, \\
 A_{\ell\ell}(\text{SM}) &= 0.048 \pm 0.004,
 \end{aligned}$$

LHC

$$\begin{aligned}
 A_C^{\ell\ell}(\text{ATLAS}, 7 \text{ TeV}) &= 0.023 \pm 0.012 \pm 0.008, \\
 A_C^{\ell\ell}(\text{CMS}, 7 \text{ TeV}) &= 0.010 \pm 0.015 \pm 0.006,
 \end{aligned}$$

- Consistently above the SM prediction but no significant excess here (previous 3 sigma excess SL AI in Dzero is gone)



Lepton vs Top Asymmetry

- In SM lepton and top FB asymmetry are correlated: lepton tends to follow top direction, A_l is smeared version of A_{tt}
- That's because in SM top pair production is unpolarized: same number of t_L and t_R is produced (no final state polarization), and same number of q_L and q_R contribute to top production (no initial state polarization)
- Beyond SM, polarization effect in top pair production may be significant. Then lepton direction is correlated not only with top kinematics but also with spins of incoming quarks and outgoing tops

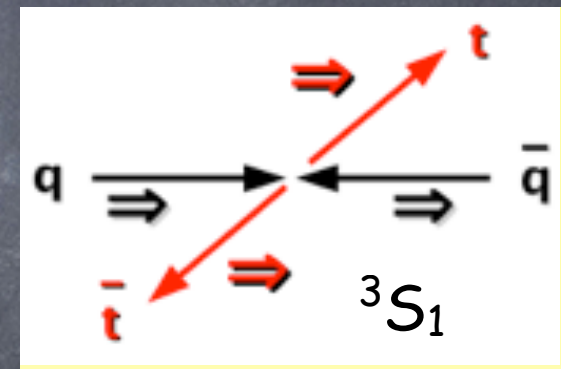
$$\frac{d\Gamma_{l+}}{d\cos\theta} \sim 1 + \cos\theta$$
$$\frac{d\Gamma_{l-}}{d\cos\theta} \sim 1 - \cos\theta$$

θ = angle between
top spin and lepton direction
in top rest frame

Lepton Asymmetry: interpretation

- Lepton asymmetry @Tevatron probes top production mechanism. Except on top asymmetry, its value depends on whether top pairs are produced dominantly by left-handed or by right-handed quarks
- The point can be made more precise at the top production threshold (@Tevatron most tops produced at threshold anyway)
- At the threshold, tops are produced in s-wave. Therefore, the sum of the top spins equals the sum of the spins of the incoming quarks
- For collisions of RH quarks and RH antiquark both spins are aligned along the proton beam. Thus top and antitop spins are both aligned along the proton beam. Therefore l^+ from top decays will preferentially go along the proton beam (and l^- from antitop - opposite to the proton beam). In an idealized situation (monochromatic quarks energies at $t\bar{t}$ threshold) lepton asymmetry would be 50%
- Analogously, for collisions of LH quarks and LH antiquarks both spins are aligned opposite to the beam. Therefore l^+ from top decays will be produced preferentially opposite to the proton beam.

AA,Perez,Schmaltz
1110.3796



Lepton vs Top Asymmetry: getting more mileage



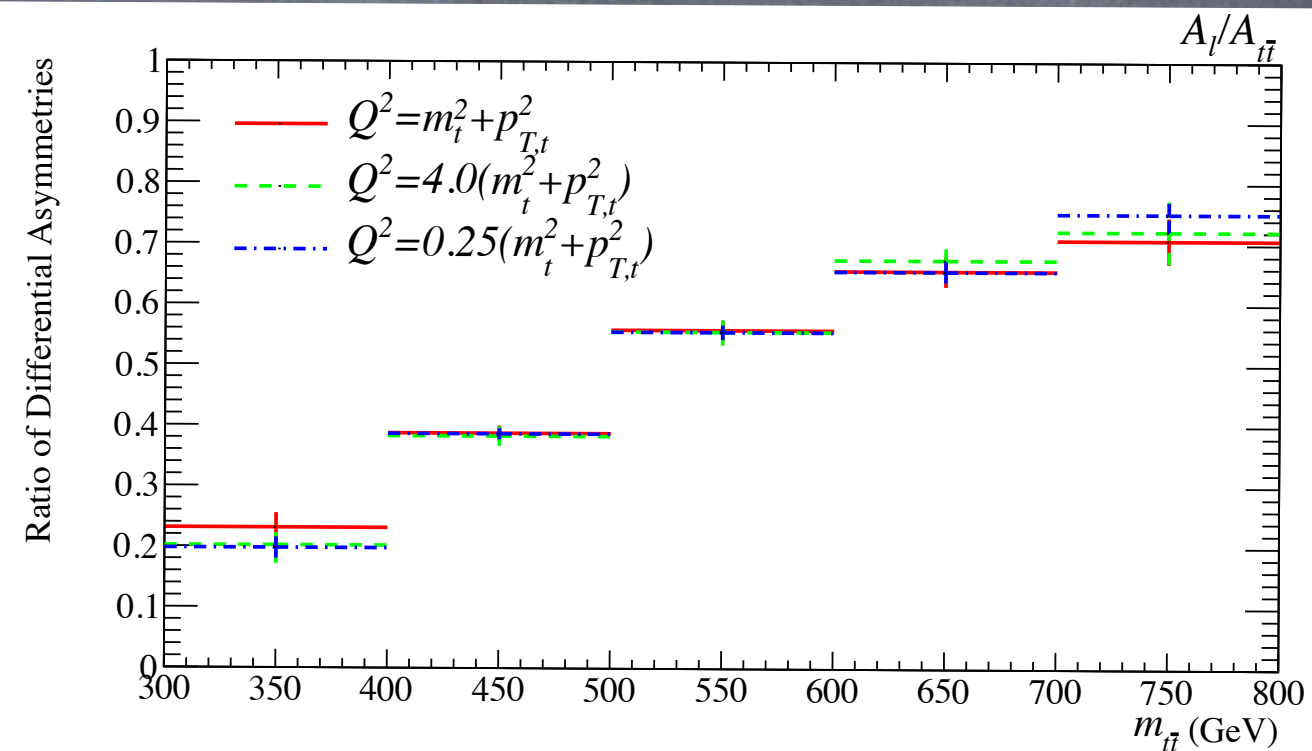
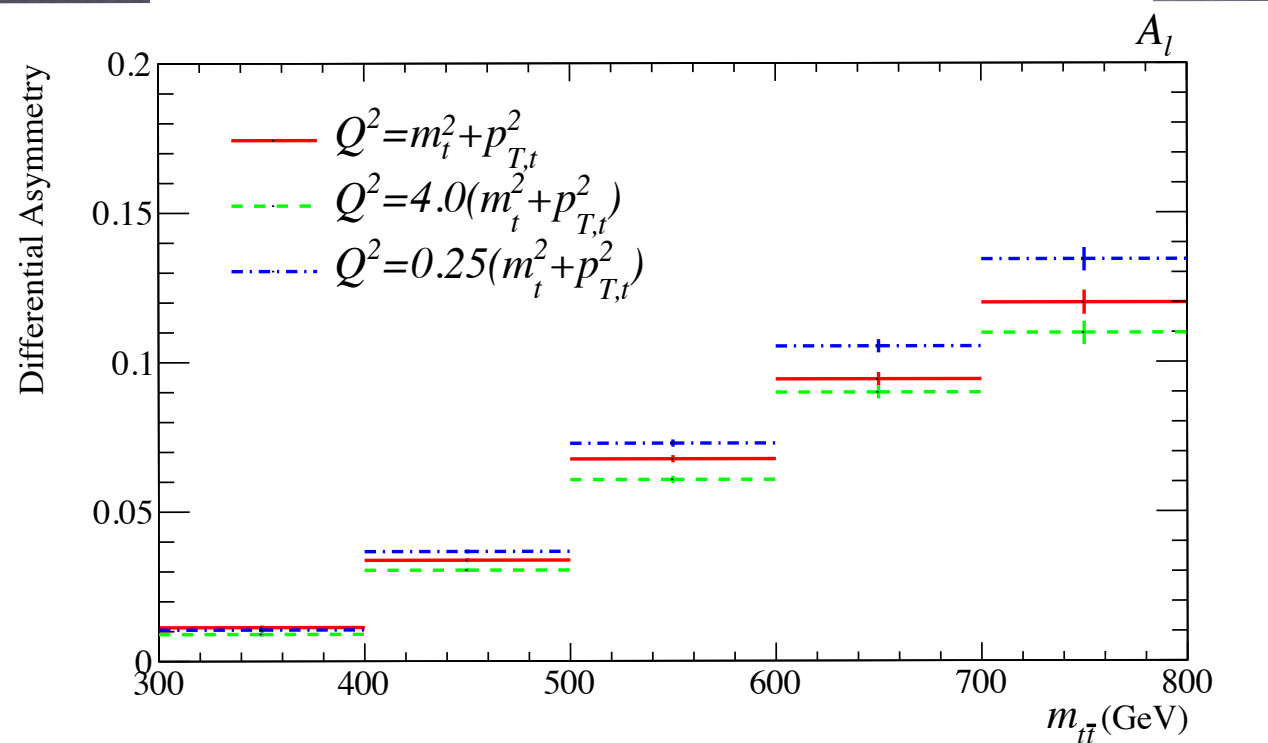
- In SM, lepton asymmetry in events is completely determined by top asymmetry, in principle in a calculable way
- This is also true differentially with respect to any kinematic variable x : in each bin of x lepton asymmetry can be determined knowing top asymmetry in that bin, such that $A_l(x)[A_{t\bar{t}}(x)]$ traces a calculable curve as x is varied
- Even if (for some reason) we got overall normalization of $A_{t\bar{t}}$ and A_l predicted by SM wrong, we may expect that the slope of the $A_l(x)[A_{t\bar{t}}(x)]$ curve is correctly predicted, since the latter depends on a relatively simple kinematics
- Beyond SM, A_l and $A_{t\bar{t}}$ become independent, therefore the shape of the $A_l(x)[A_{t\bar{t}}(x)]$ curve may be completely different
- Robust and potentially interesting test of the SM !

AA, Mangano, Martin, Perez, Winter, [[arXiv:1212.4003](#)]

Carmona et al. [[arXiv:1401.2443](#)]

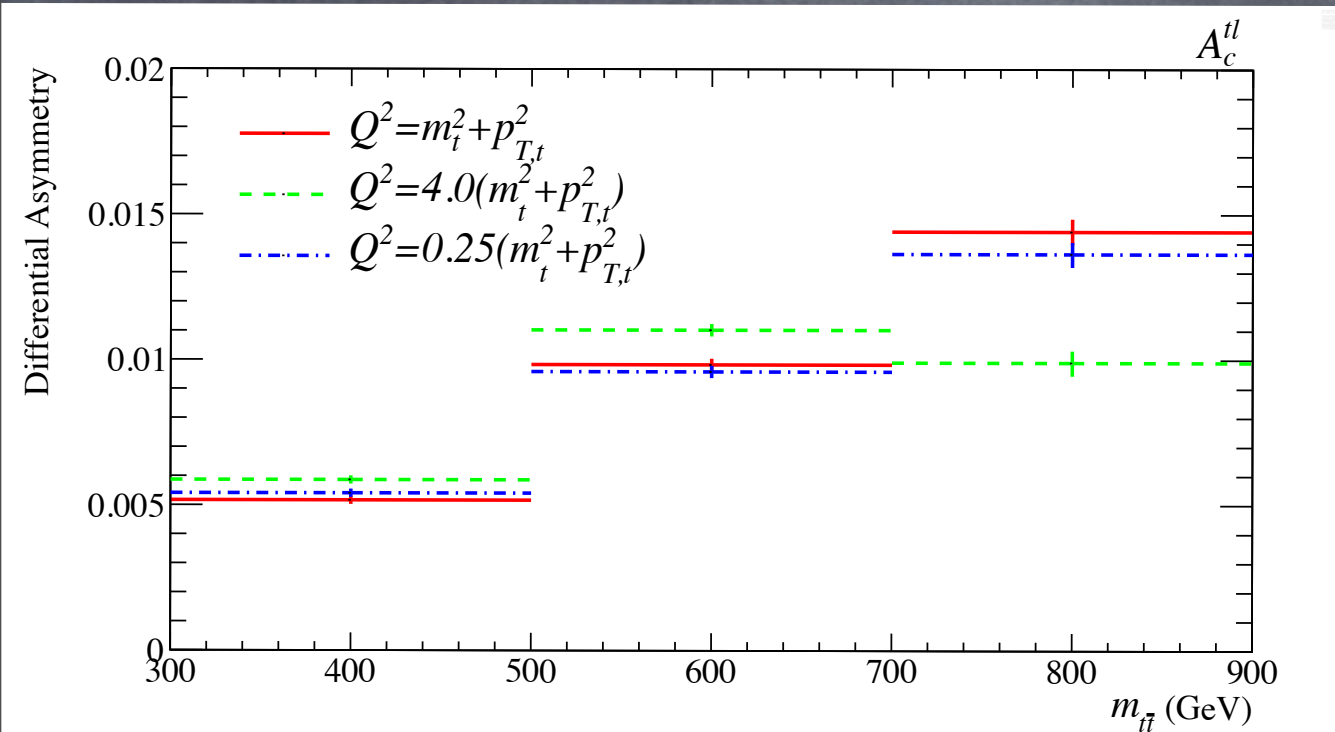
Lepton vs Top Asymmetry: example at Tevatron

$$A_\ell = \frac{N(q \times \eta > 0) - N(q \times \eta < 0)}{N(q \times \eta > 0) + N(q \times \eta < 0)},$$

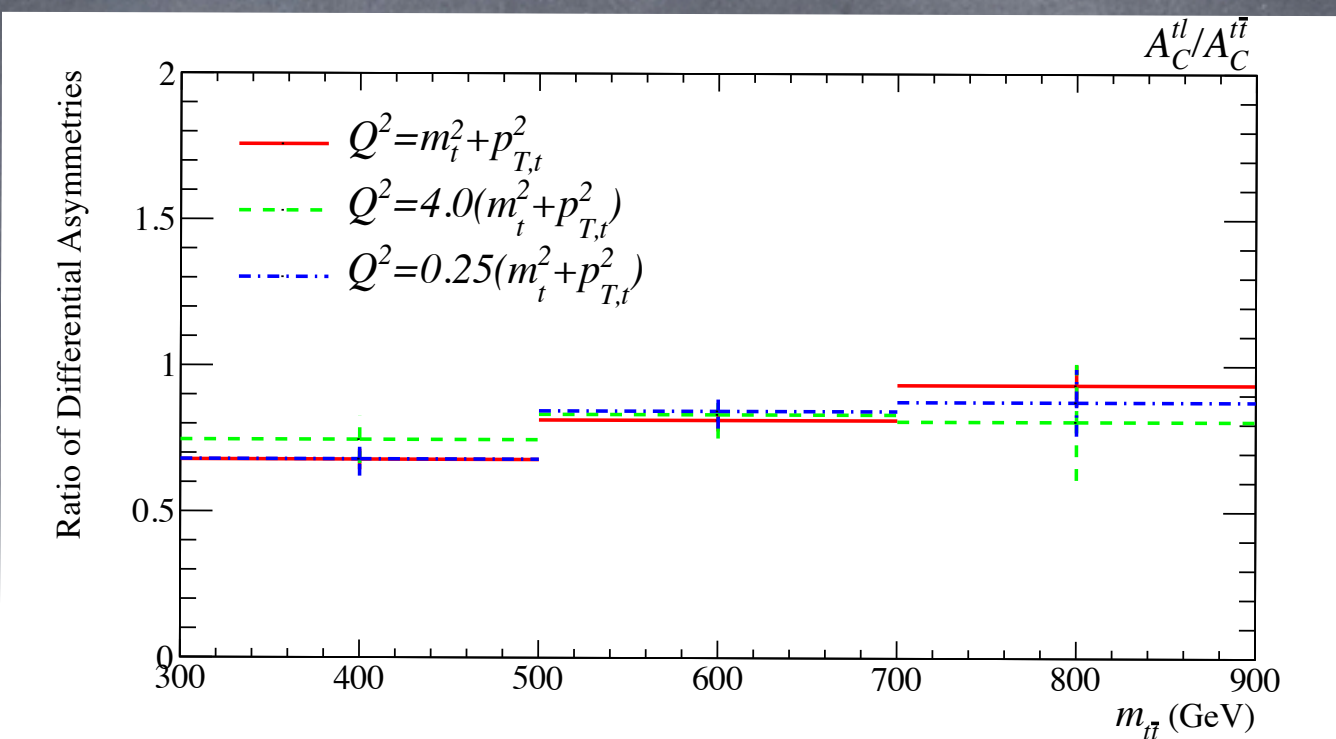


- Individual top and lepton asymmetries as function of $m_{t\bar{t}}$ have large scale dependence
- Ratio of the two has smaller uncertainty
- Many more robustness tests (cuts, reconstruction effects, additional radiation)
- Also works when plotted against p_T of the lepton in semileptonic $t\bar{t}$ decays

Lepton vs Top Asymmetry: example at LHC



$$A_C^{t\ell} = \frac{N(\Delta|y|^{t\ell} > 0) - N(\Delta|y|^{t\ell} < 0)}{N(\Delta|y|^{t\ell} > 0) + N(\Delta|y|^{t\ell} < 0)},$$



- Individual top and lepton asymmetries as function of $m_{t\bar{t}}$ have large scale dependence
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Lepton vs Top Asymmetry

- Overall, good theoretical control of the SM predictions
- How can this help discover BSM physics?

Lepton vs Top Asymmetry: $p_T(\text{lepton})$ dependence

BSM physics may affect $p_T(l)$ distributions of asymmetries in 3 ways:

- 1) **Mttbar dependence.** Dependence of asymmetries on t - $tbar$ invariant mass is typically different in BSM models, and then $p_T(l)$ dependence is also affected due to correlation between m_{tt} and $p_T(l)$
- 2) **Initial state polarization.** Different contribution of left- and right-handed quarks to t - $tbar$ production leads to A_l becoming uncorrelated from A_{tt} especially at low $p_T(l)$
- 3) **Final state polarization.** Overall polarization of t - $tbar$ pairs changes correlation between lepton and top direction for boosted top, and between $p_T(l)$ and t - $tbar$ invariant mass

Axigluon model

New heavy colored octet with chiral couplings to quarks:

$$\mathcal{L} \supset g_{L,i} \bar{q}_i \gamma^\mu G_\mu^a T^a P_L q_i + g_{R,i} \bar{q}_i \gamma^\mu G_\mu^a T^a P_R q_i ,$$

Benchmarks

Axi200R : $m_G = 200 \text{ GeV}, \quad \Gamma_G = 50 \text{ GeV}, \quad g_{R,i} = 0.5g_s, \quad g_{L,i} = 0;$
Axi200L : $m_G = 200 \text{ GeV}, \quad \Gamma_G = 50 \text{ GeV}, \quad g_{R,i} = 0, \quad g_{L,i} = 0.5g_s;$
Axi200A : $m_G = 200 \text{ GeV}, \quad \Gamma_G = 50 \text{ GeV}, \quad g_{R,i} = 0.4g_s, \quad g_{L,i} = -0.4g_s,$

light

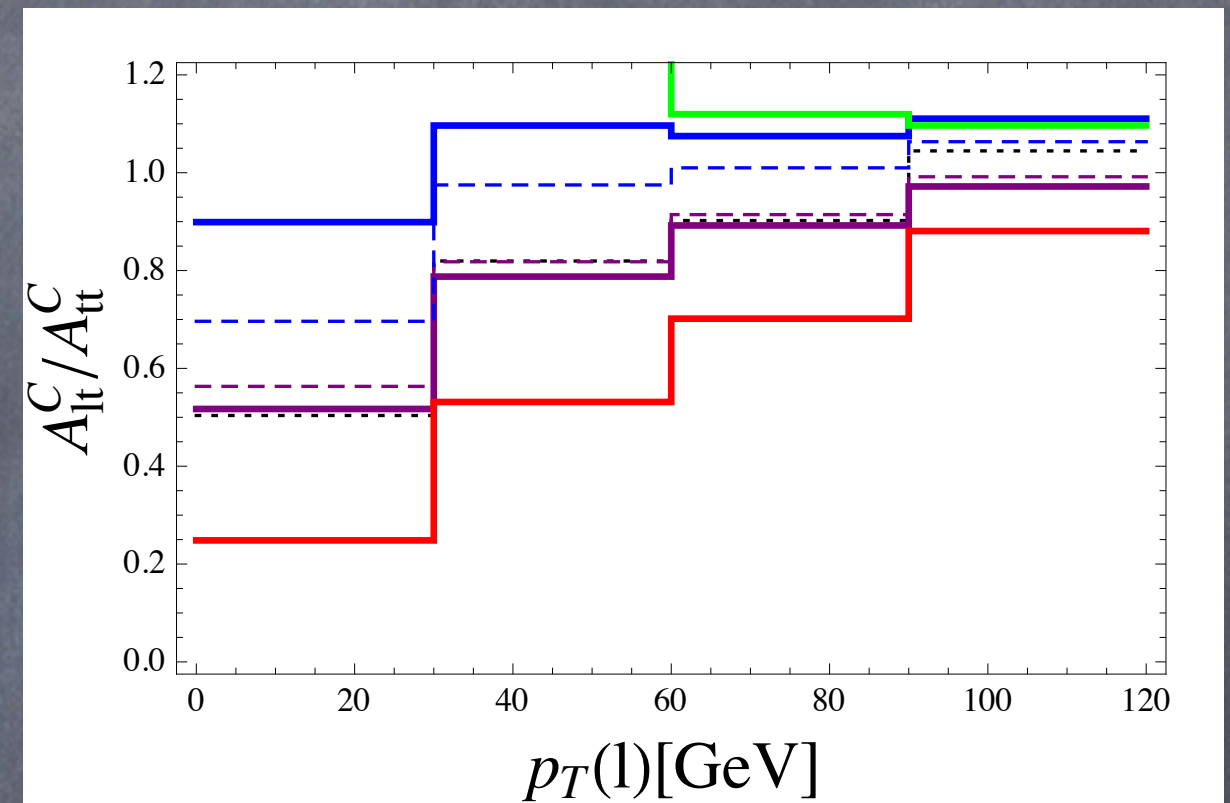
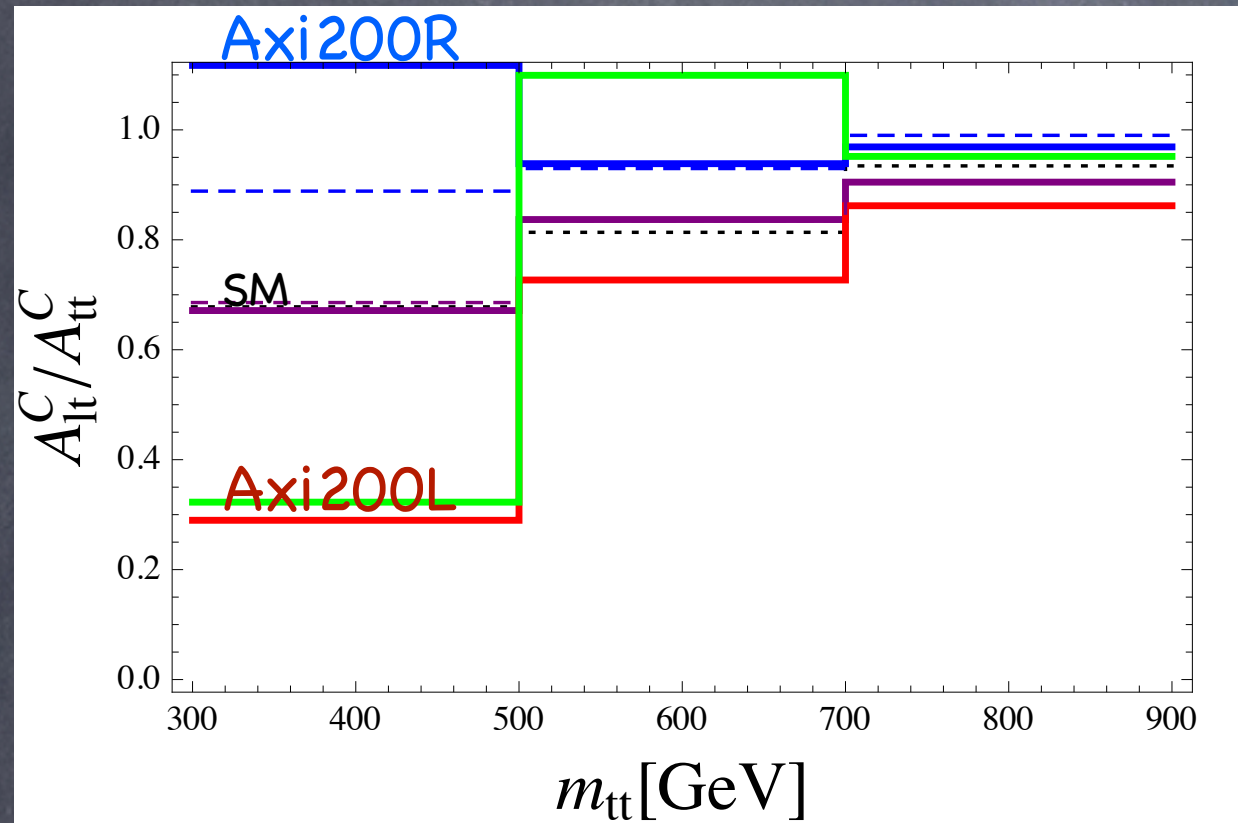
Axi2000A : $m_G = 2 \text{ TeV}, \quad \Gamma_G = 0.96 \text{ TeV}, \quad g_{R,u} = -g_{L,q_1} = -0.6g_s, \quad g_{R,t} = -g_{L,t} = 4g_s;$
Axi2000R : $m_G = 2 \text{ TeV}, \quad \Gamma_G = 1.0 \text{ TeV}, \quad g_{R,u} = -0.8g_s, \quad g_{R,t} = 6g_s, \quad g_{L,i} = 0.$

heavy

Benchmark	$\Delta A_{t\bar{t}}$	ΔA_ℓ	$\Delta A_C^{t\bar{t}}$	$\Delta A_C^{t\ell}$
Axi200R	0.05	0.07	0.006	0.009
Axi200L	0.05	-0.03	0.007	0.001
Axi200A	0.12	0.05	0.016	0.012
Axi2000R	0.04	0.05	0.007	0.009
Axi2000A	0.07	0.04	0.012	0.010

Axigluon model

Ratio of top and lepton asymmetries at LHC



- Ratio is a good discriminating variable, especially at low m_{tt} and also low p_T lepton

To Take Away

- Top and leptonic FB asymmetries are strongly correlated in the SM but independent observables in the presence of BSM contributions to top pair production
- Lepton asymmetry near the t - t bar threshold measures polarization of the light quarks that produce the t - t bar pairs
- Studying correlation of A_{++} and A_l as function of other kinematic observables, in particular as function of $p_T(\text{lepton})$, provides another test of the SM and additional discriminating power for new physics
- Light Axigluon at the ILC? Axigluons radiated off final state quarks can be searched for

