Adam Falkowski

Top Asymmetry

vs

Lepton Asymmetry

Zurich, 8 January 2013

Based on work with M. Mangano, A. Martin, G. Perez and J. Winter, [arXiv:1212.4003]

Top Asymmetry

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

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

- Anomalous t-tbar forward-backward asymmetry at the Tevatron remains one of the most promising hints of new physics
- So far related LHC asymmetry observables perfectly consistent with the SM, but still ample room for new physics

Top Asymmetry: Data

Inclusive asymmetry, naive CDF/D0 combination

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

High mttbar asymmetry @CDF 9fb-1, 1211.1003

Smaller number in D0 but not unfolded to parton level

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

Inclusive asymmetry @Tevatron, SM prediction

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

High mttbar asymmetry @ Tevatron, SM prediction

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

For review see Rodrigo, arXiv:1207.0331

~2.5σ deviation from the SM

Closely related charge asymmetry @LHC

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

Charge asymmetry @LHC, SM prediction

$$A_{C,t\bar{t}}^{\text{SM}} \approx 0.01$$

Charge asymmetry dilepton channel @ATLAS 5fb-1, ATLAS-CONF-2012-057

$$A_{C,t\bar{t}} = 0.057 \pm 0.028$$

Charge asymmetry in dilepton channel @CMS 5fb-1 CMS PAS TOP-12-010

$$A_{C,t\bar{t}} = 0.050^{+0.044}_{-0.058}$$

Charge asymmetry semileptonic channel @CMS 5fb-1 [arXiv:1207.0065]

$$A_{C,t\bar{t}} = 0.004 \pm 0.015$$

Charge asymmetry semileptonic channel @ATLAS 1fb-1 [arXiv:1203.4211]

$$A_{C,t\bar{t}} = -0.018 \pm 0.036$$

Lepton Asymmetry: Data

Lepton asymmetry in t-tbar @Tevatron
(semileptonic or dileptonic channel)

$$A_l = \frac{N(q_l\eta_l > 0) - N(q_l\eta_l < 0)}{N(q_l\eta_l > 0) + N(q_l\eta_l < 0)}$$

Frame dependent

Lepton asymmetry semileptonic channel
@D0 5fb-1, LAB frame, 1107.4995]

$$A_l = 0.15 \pm 0.04$$

Smaller number in CDF but not unfolded to parton level

Lepton asymmetry @ Tevatron/LAB, SM prediction

$$A_l^{\rm SM} \approx 0.02$$

~3σ deviation from the SM

Related observables:

Dilepton asymmetry in dileptonic t-tbar @Tevatron

$$A_{ll} = \frac{N(y_{l^+} > y_{l^-}) - N(y_{l^+} < y_{l^-})}{N(y_{l^+} > y_{l^-}) + N(y_{l^+} < y_{l^-})}$$

Longitudinal boost independent

Dilepton asymmetry @CDF, 5fb-1
CDF NOTE 10436 (2011)

$$A_{ll} = 0.42 \pm 0.16$$

Dilepton asymmetry @Tevatron, SM prediction

$$A_{ll}^{\rm SM} \approx 0.06$$

Dilepton charge asymmetry in dileptonic t-tbar @LHC

$$A_{C,ll} = \frac{N(|y_{l^+}| > |y_{l^-}|) - N(|y_{l^+}| < |y_{l^-}|)}{N(|y_{l^+}| > |y_{l^-}|) + N(|y_{l^+}| < |y_{l^-}|)}$$

Dilepton charge asymmetry @ATLAS
ATLAS-CONF-2012-057

$$A_{C,ll} = 0.023 \pm 0.014$$

Dilepton charge asymmetry @LHC, SM prediction

$$A_{C,ll}^{\rm SM} \approx 0.005$$

Lepton vs Top Asymmetry

- In SM lepton and top FB asymmetry are correlated: lepton tends to follow top direction, Al is smeared version of Att

- That's because in SM top pair production is unpolarized: same number of tL and tR is produced (no final state polarization), and same number of qL and qR contribute to top production (no initial state polarization)

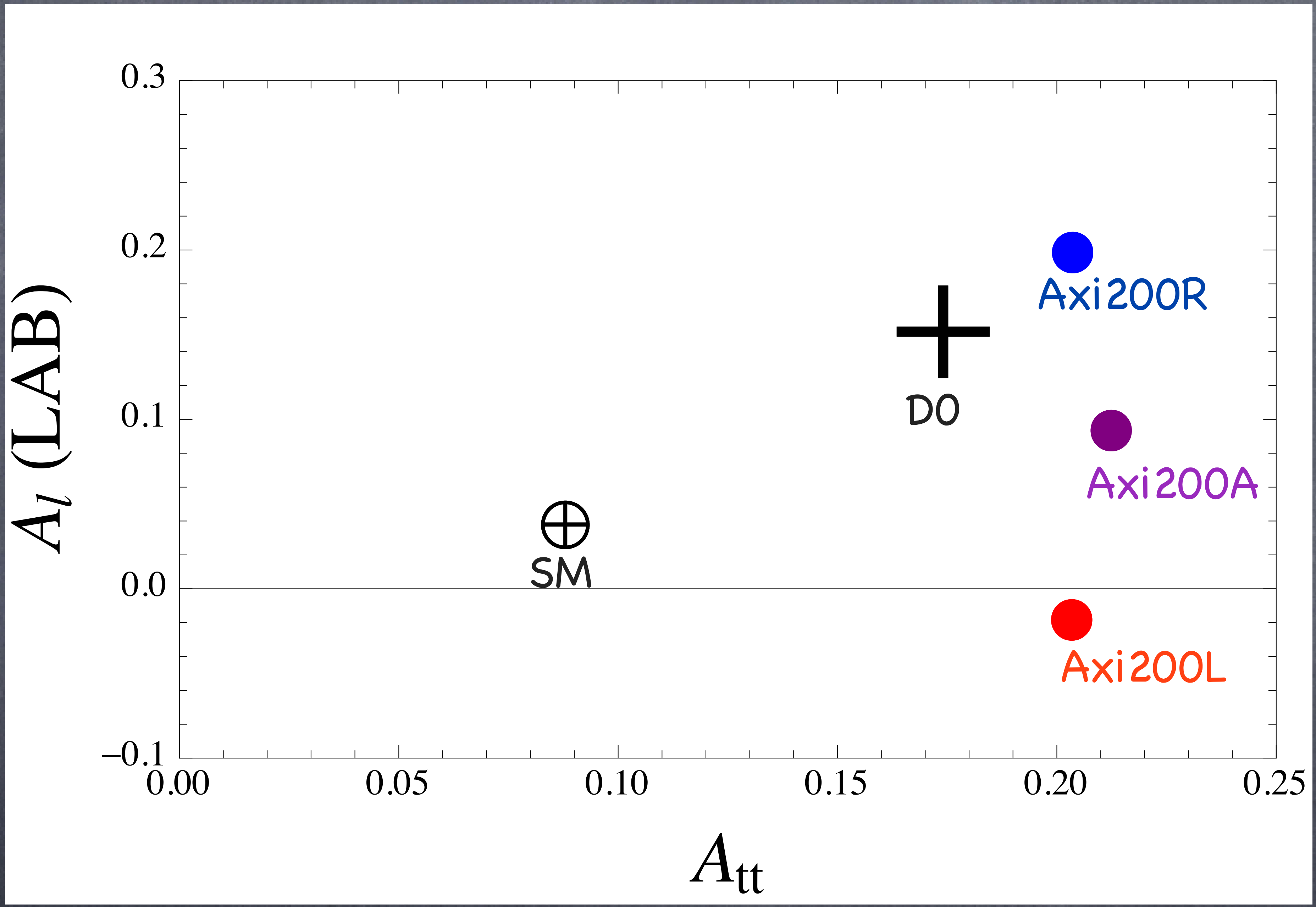
- Beyond SM, polarization effect in top pair production may be significant. Then lepton direction is correlated not only with top kinematics but also with its spin

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

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

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

Lepton vs Top Asymmetry



Beyond SM, lepton and top asymmetry are independent observables; they can even have different sign

Lepton asymmetry can help discriminating between different BSM models predicting same top asymmetry

Krohn et al, 1105.3743

Lepton Asymmetry: interpretation

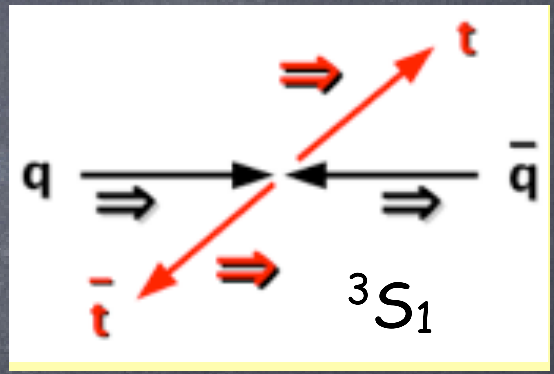
- Lepton asymmetry @Tevatron probes top production mechanism. Except on top asymmetry, its value depends on whether top pairs are produced dominantly by left-handed or by right-handed quarks

- The point can be made more precise at the top production threshold (@Tevatron most tops produced at threshold anyway)

AA,Perez,Schmaltz
1110.3796

- 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 ttbar 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.

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 $A_l(x)[A_{tt}(x)]$ traces a calculable curve as x is varied

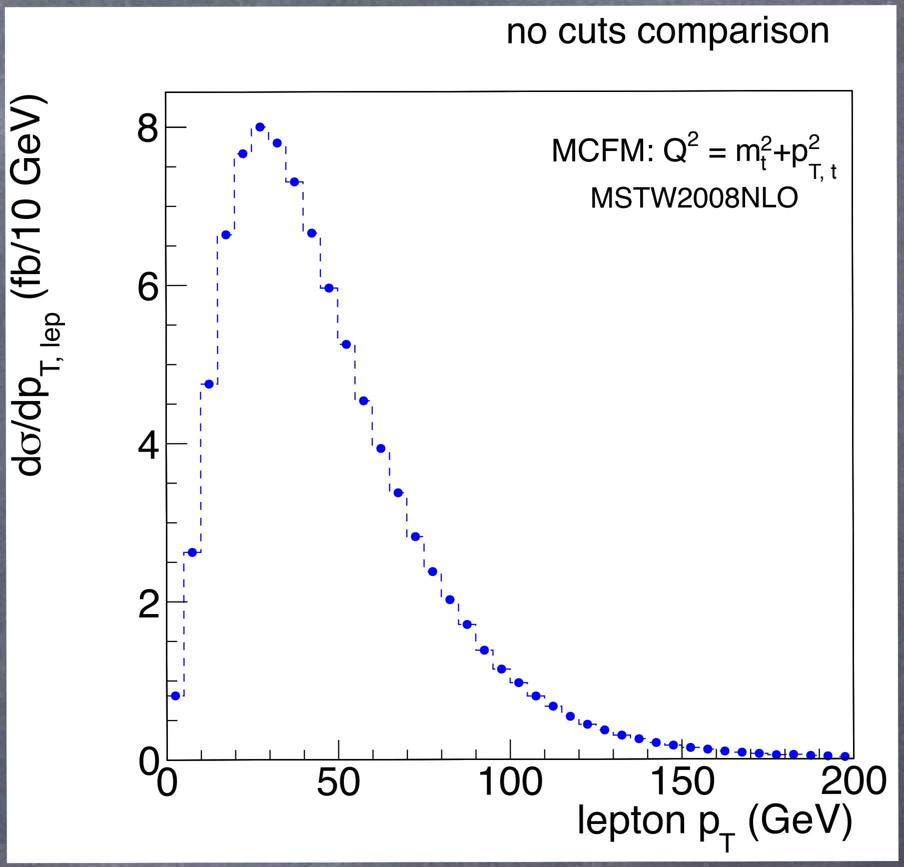
- Even if (for some reason) we got overall normalization of A_{tt} and A_l predicted by SM wrong, we may expect that the slope of the $A_l(x)$ $[A_{tt}(x)]$ curve is correctly predicted, since the latter depends on a relatively simple kinematics

- Beyond SM, A_l and A_{tt} become independent, therefore the shape of the $A_l(x)[A_{tt}(x)]$ curve may be completely different

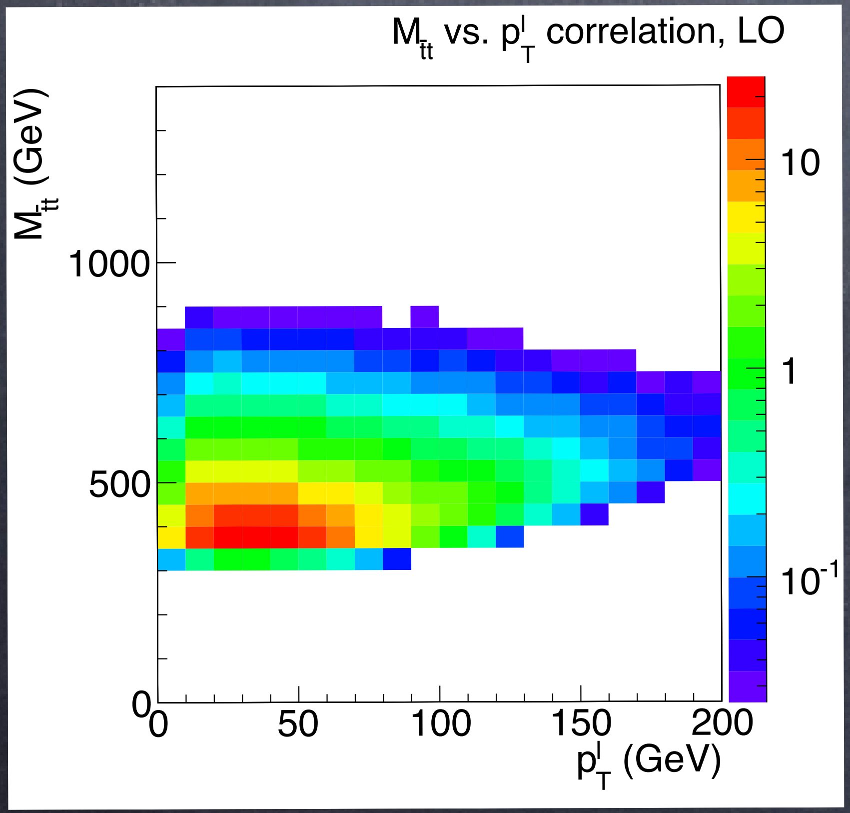
- Robust and potentially interesting test of the SM !

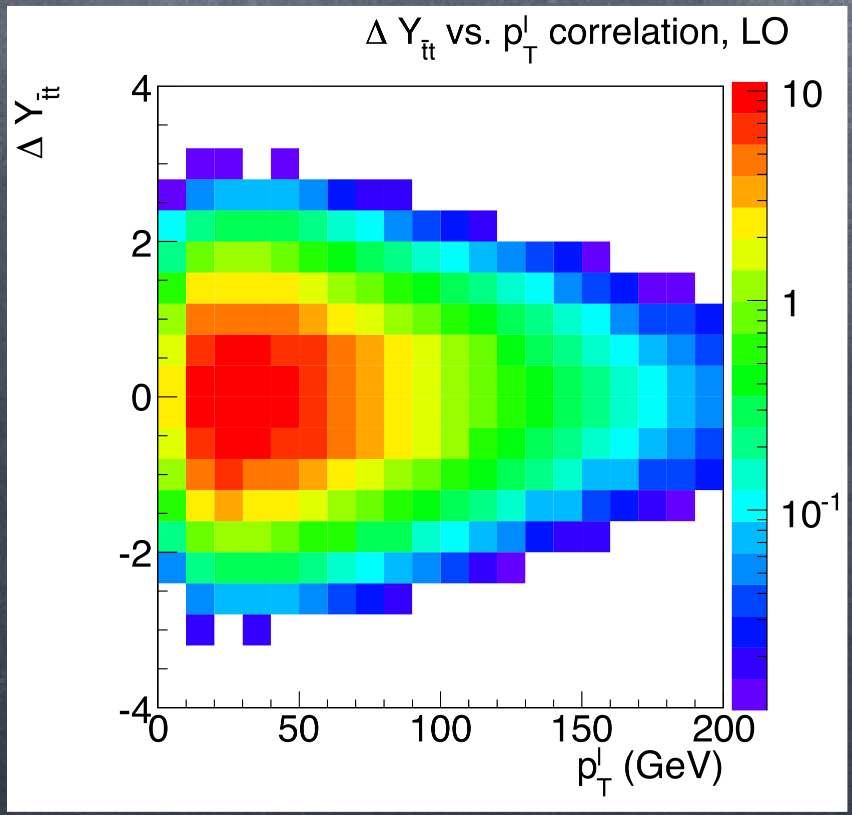
Lepton vs Top Asymmetry: pT(lepton) dependence

AA, Mangano, Martin, Perez, Winter, [arXiv:1212.4003]



- I will argue it is advantageous to take pT(l) in semi-leptonic t-tbar sample as our "x" variable
- Experimentally clean and simple observable
- Related in an intuitive way to top kinematics
- Provides good discrimination between SM and BSM, and between different BSM models

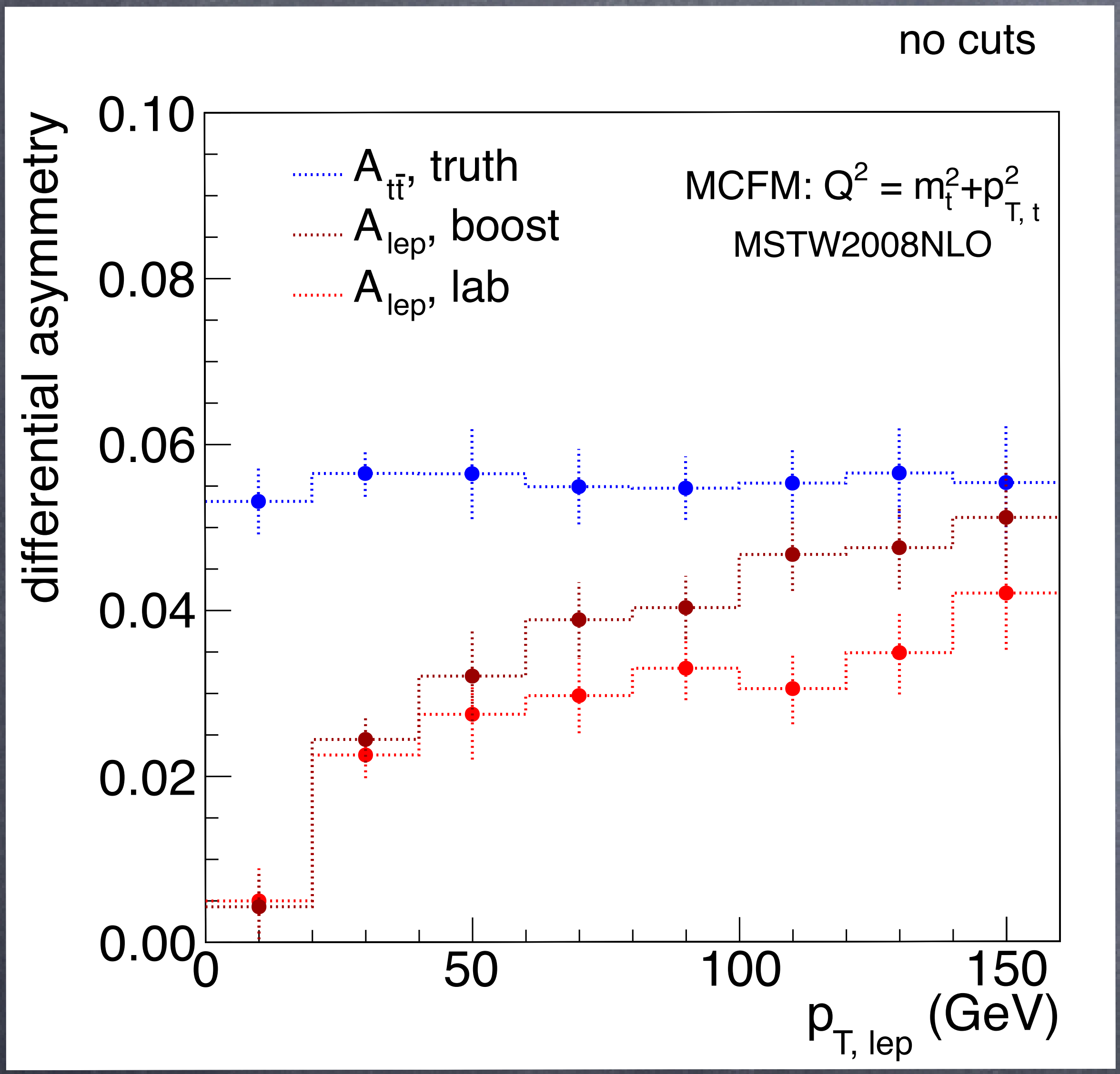




Here only Tevatron asymmetries, and only semileptonic t-tbar. Extension to LHC observables and dileptonic tops should be straightforward

Lepton vs Top Asymmetry: pT(lepton) dependence

SM predictions from NLO MCs

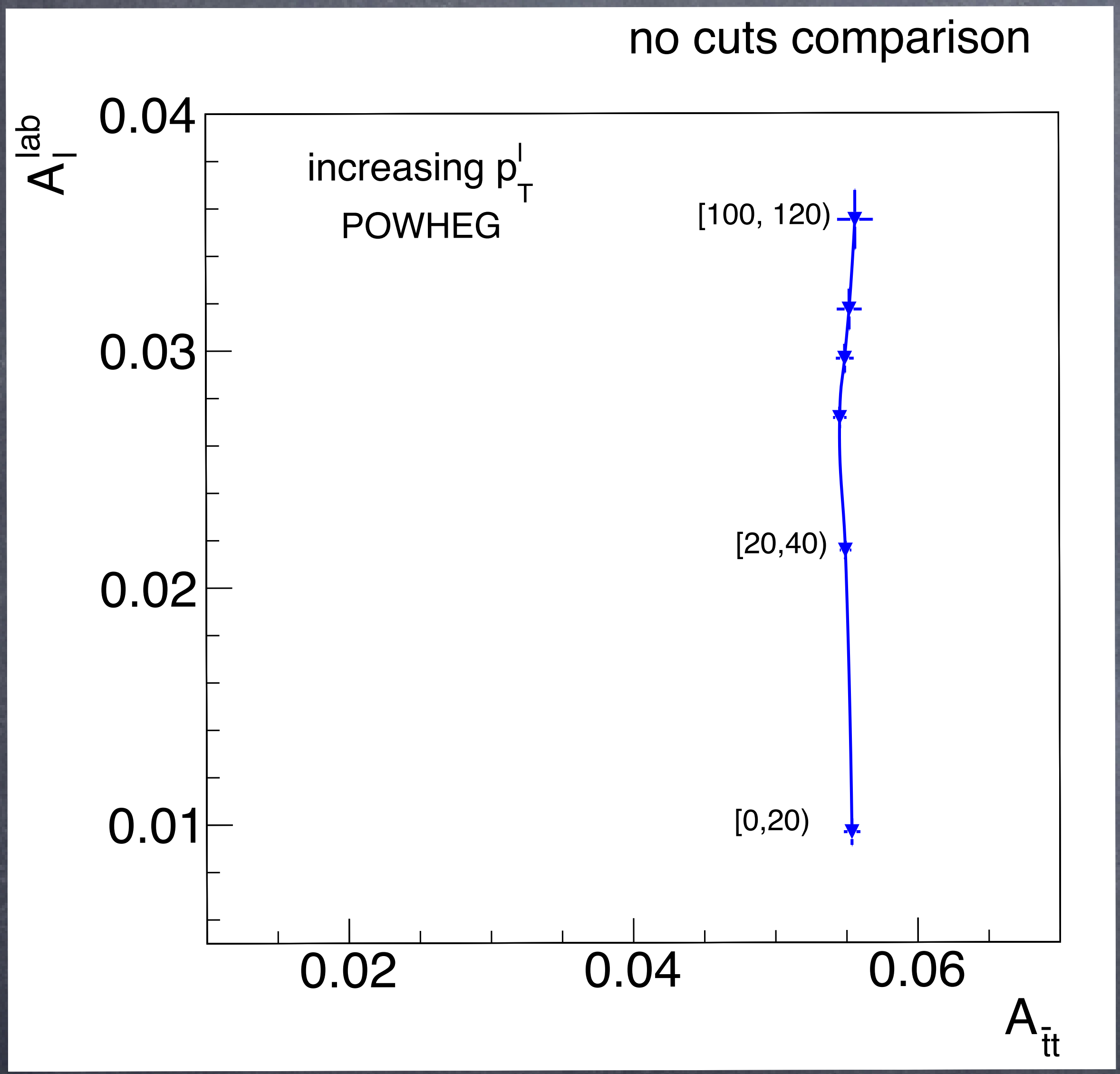


Lepton asymmetry in the frame where t-tbar pair has no longitudinal momentum behaves a bit more intuitively, but is a bit more difficult experimentally

- Start with simplest case: parton level, no showering, no detector effects, no experimental cuts
- At small pT(l) lepton asymmetry starts at low value (because of no polarization of initial state)
- At high pT(l) lepton asymmetry asymptotes to top asymmetry (because of simple kinematics)
- Incidentally, top asymmetry almost constant as function of pT(l) (effects of pT(l) correlation with m_tt canceled by anti-correlation with Δy_tt)

Lepton vs Top Asymmetry: pT(lepton) dependence

SM predictions from NLO MCs

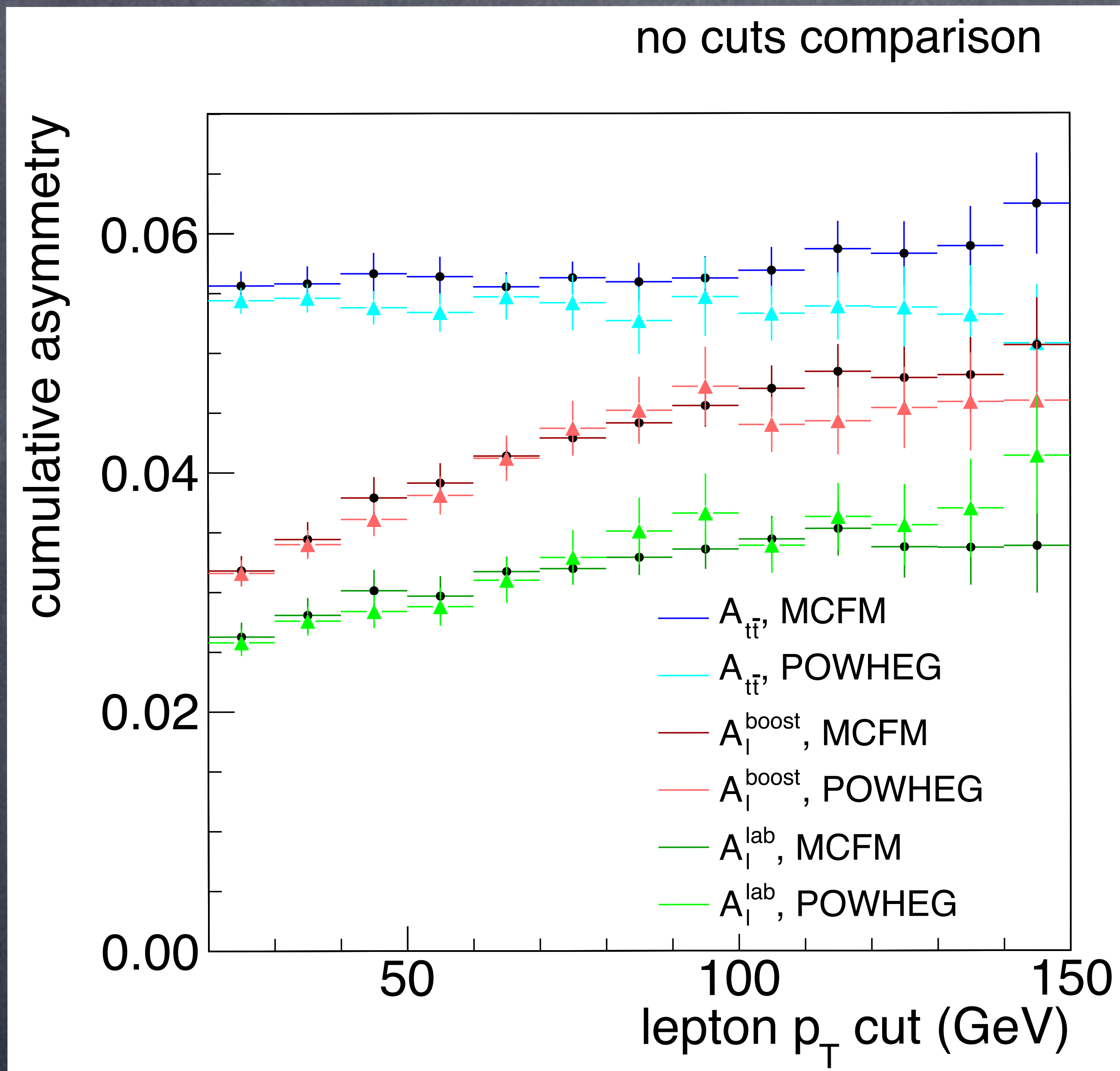


Same as before, but MCFM→POWHEG and plotted differently

- Start with simplest case: parton level, no showering, no detector effects, no experimental cuts
- At small pT(l) lepton asymmetry starts at low value (because of no polarization of initial state)
- At high pT(l) lepton asymmetry asymptotes to top asymmetry (because of simple kinematics)
- Incidentally, top asymmetry almost constant as function of pT(l) (effects of pT(l) correlation with m_tt canceled by anti-correlation with Δy_tt)

Lepton vs Top Asymmetry: pT(lepton) dependence

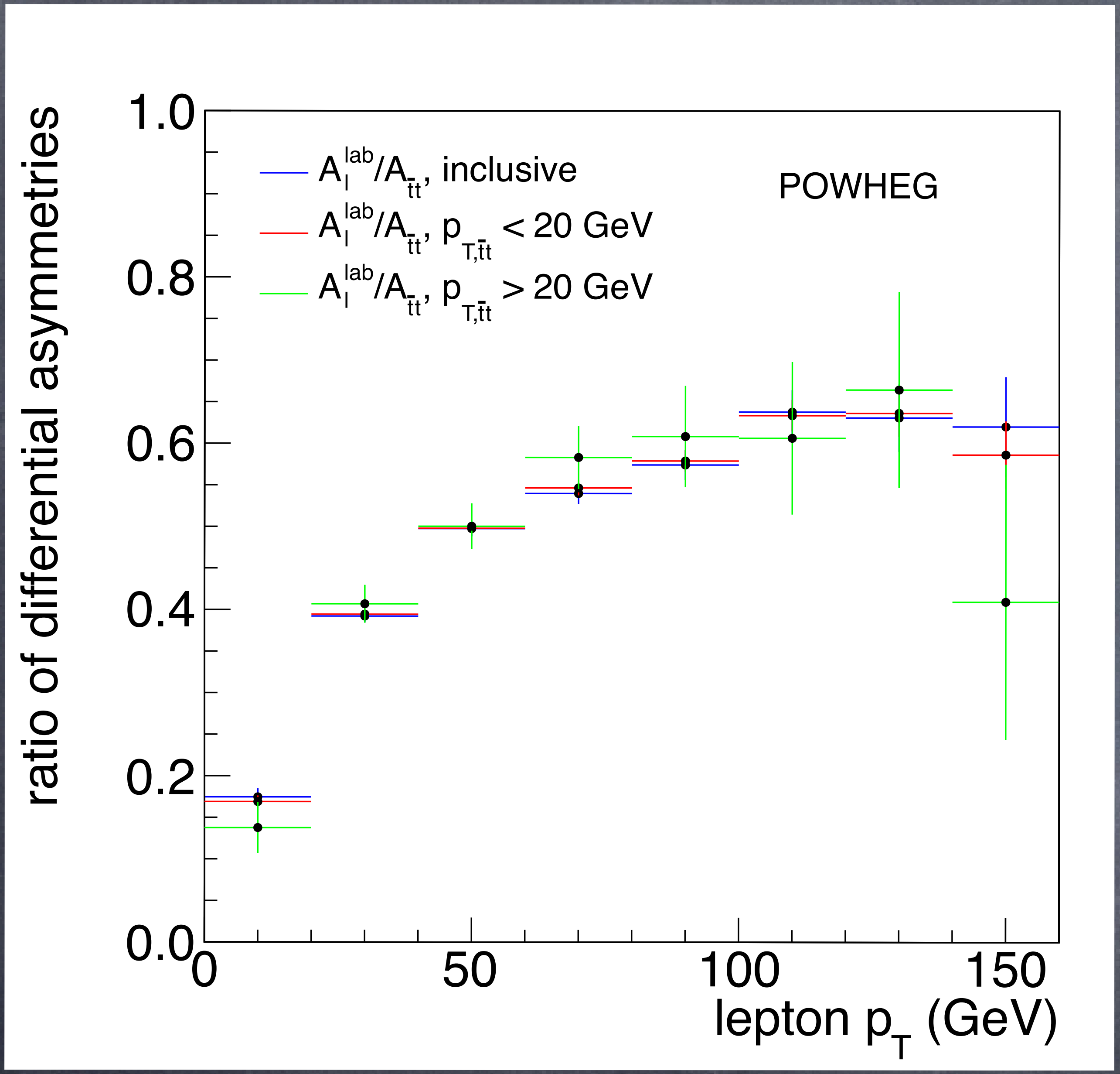
Are SM predictions robust?



MCFM and POWHEG agree very well within MC statistical errors

Lepton vs Top Asymmetry: pT(lepton) dependence

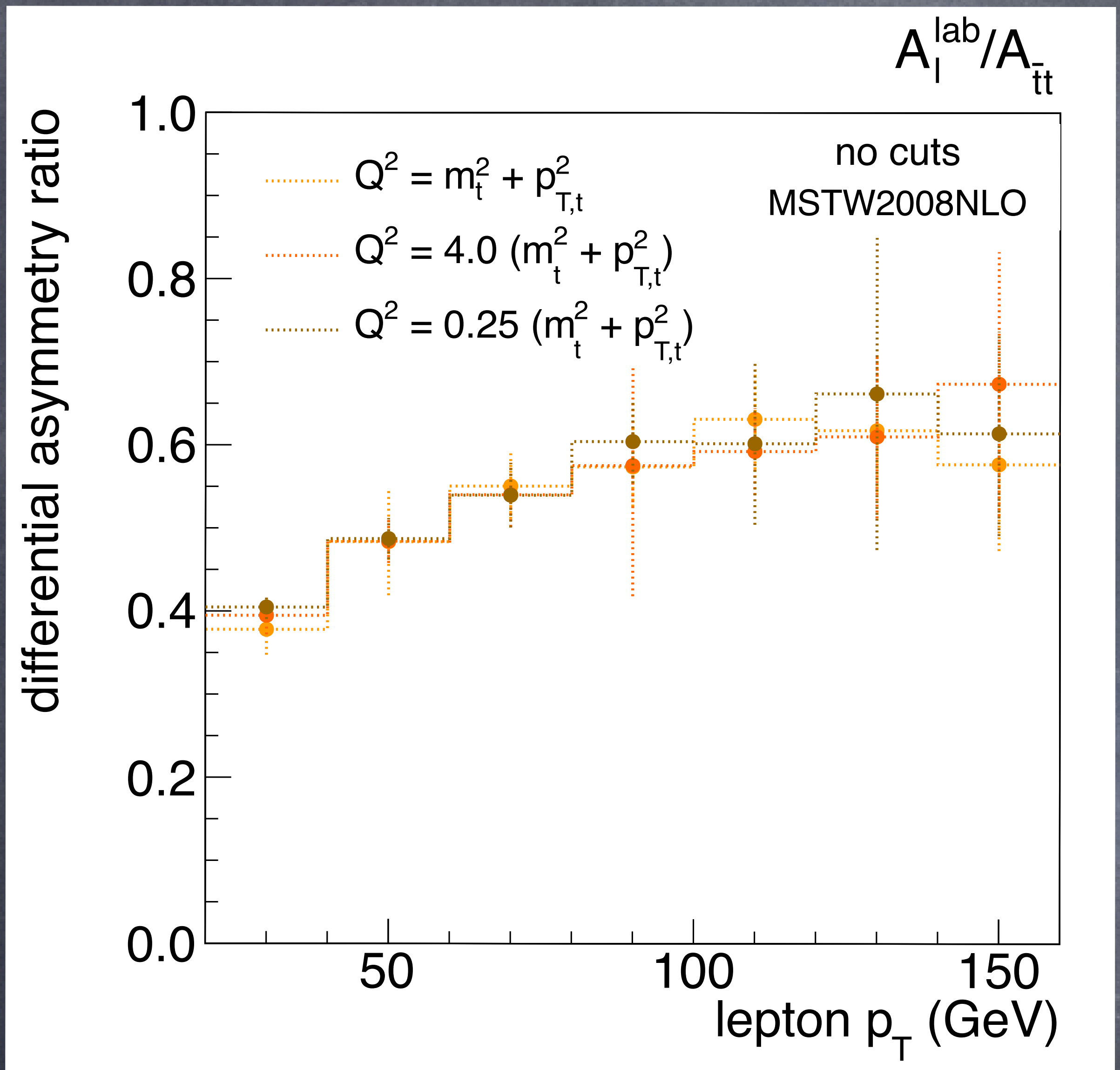
Are SM predictions robust?



The ratio of A_l and A_{tt} is not sensitive to transverse momentum of t-tbar pair

Lepton vs Top Asymmetry: pT(lepton) dependence

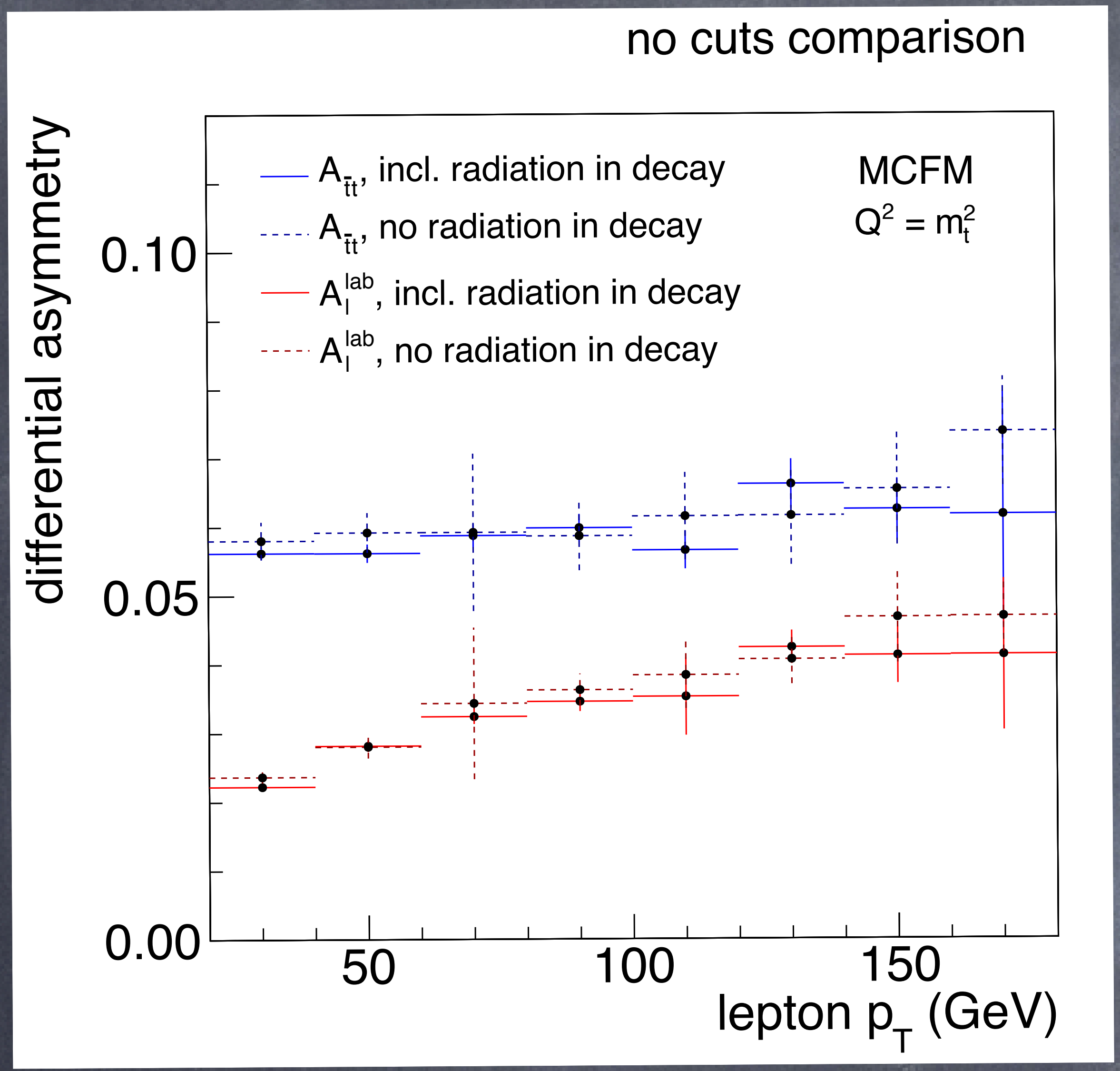
Are SM predictions robust?



The ratio of A_l and A_{tt} is not sensitive to variation of renormalization scale

Lepton vs Top Asymmetry: pT(lepton) dependence

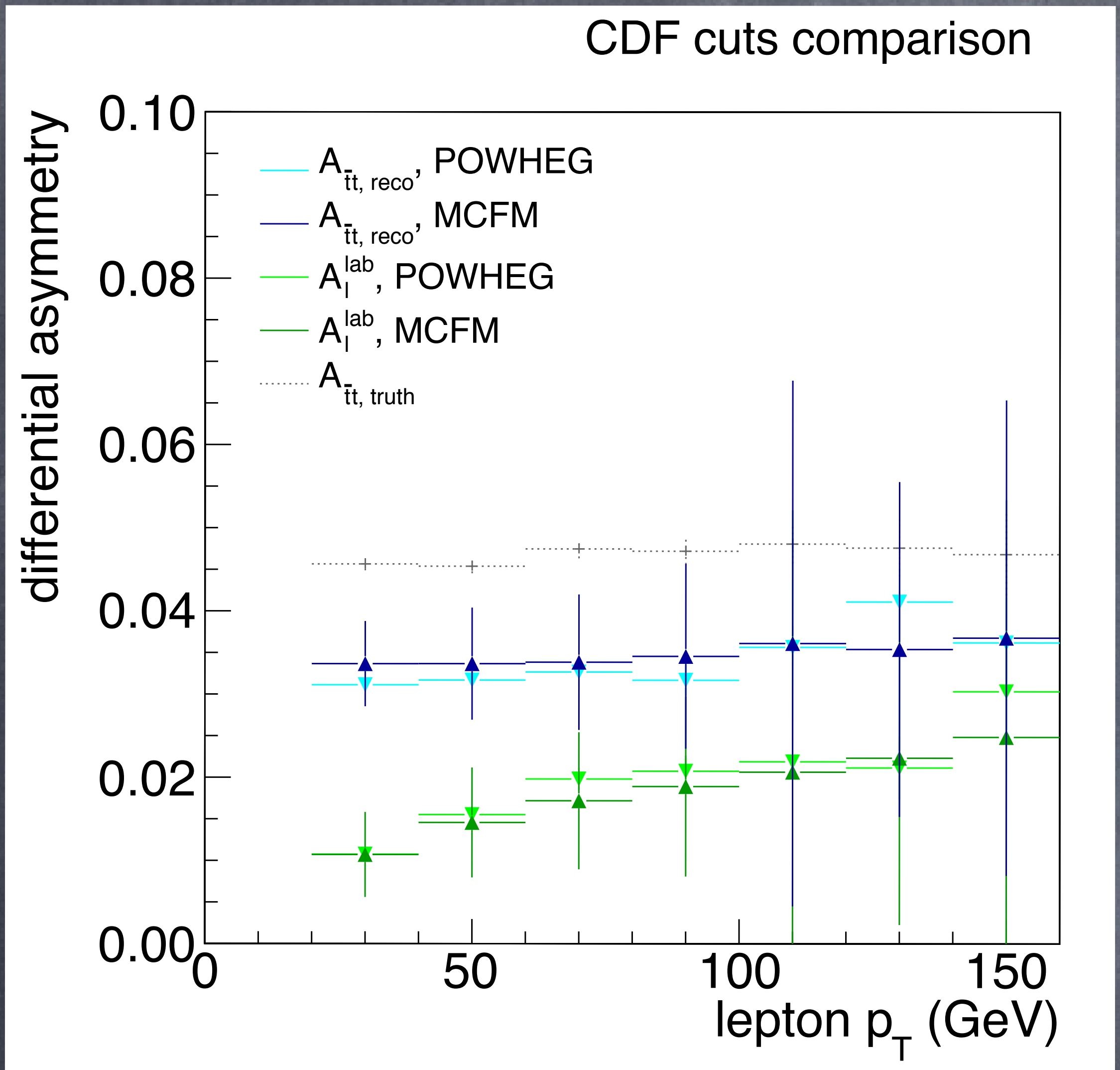
Are SM predictions robust?



Asymmetries are not sensitive to radiation in top decay

Lepton vs Top Asymmetry: pT(lepton) dependence

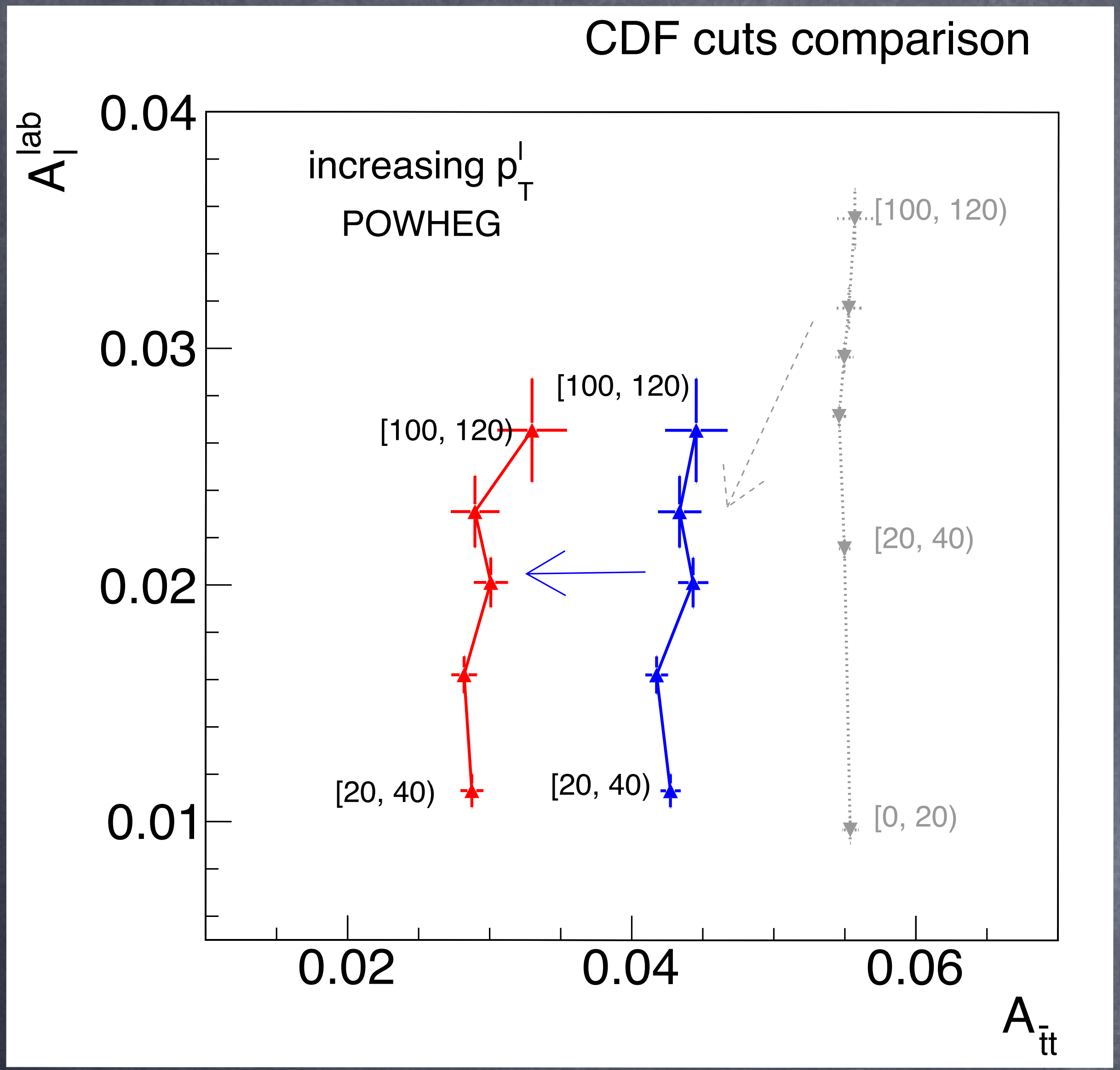
Are SM predictions robust?



Imposing experimental cuts on jet and lepton pT and rapidity changes normalization of asymmetry but keeps shape of A_{tt}[pT(l)] and A_l[pT(l)] unchanged

Lepton vs Top Asymmetry: pT(lepton) dependence

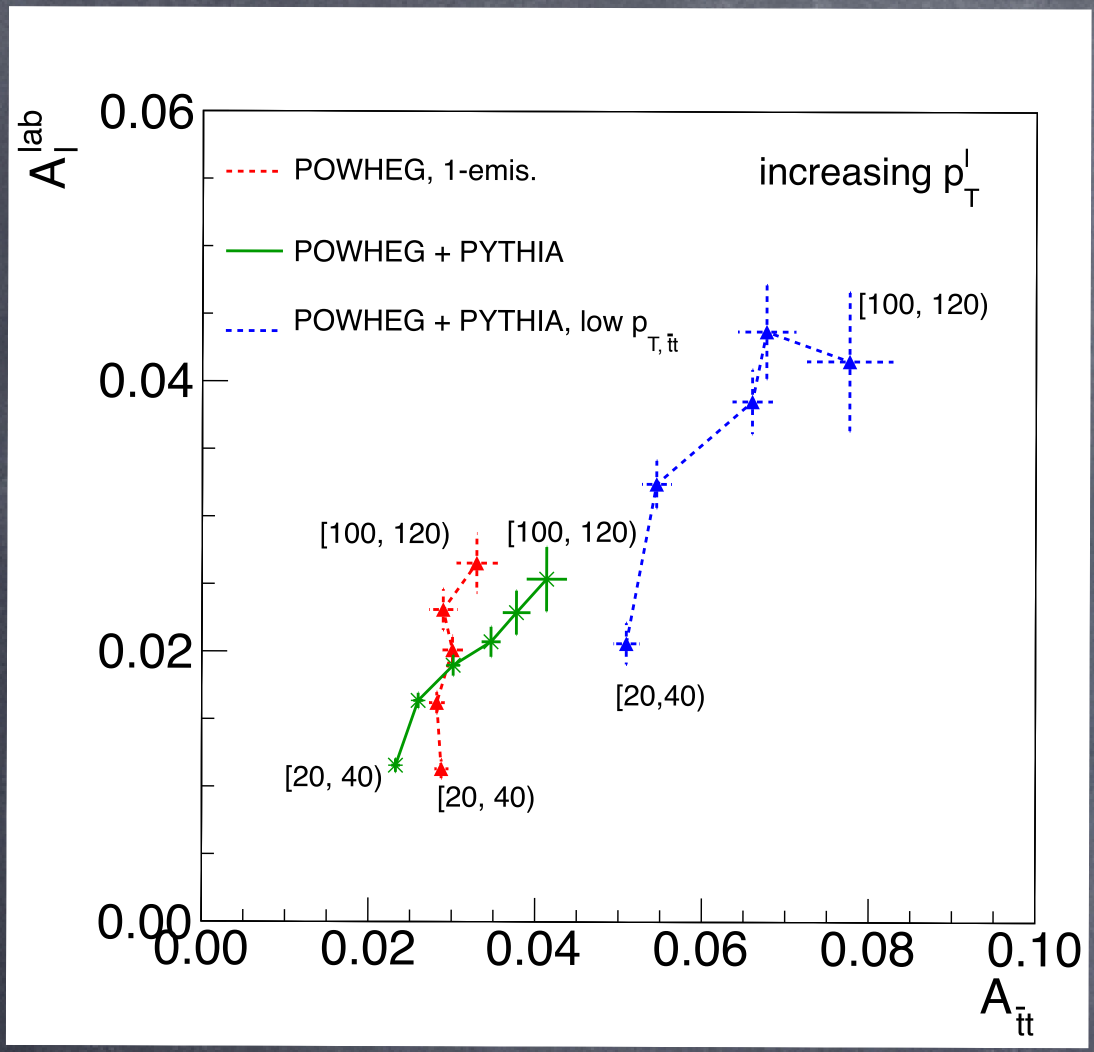
Are SM predictions robust?



Experimental cuts on jet and lepton pT and rapidity, as well as top reconstruction, change normalization of asymmetry but keeps shape of A_{tt}[pT(l)] and A_l[pT(l)] unchanged

Lepton vs Top Asymmetry: pT(lepton) dependence

Are SM predictions robust?



Showering effects change slightly the slope of the $A_l[A_{tt}(pT(l))]$ curve :-(they affect A_{tt} and almost do not touch A_l)

Also, problems with modeling emission using SHERPA, see paper

Lepton vs Top Asymmetry: pT(lepton) dependence

Are SM predictions robust?

- Overall, good theoretical control of the SM predictions for the shape of the $A_l[A_{tt}(pT(l))]$ curve
- How can this help discover BSM physics?

Lepton vs Top Asymmetry: pT(lepton) dependence

Example BSM benchmarks

Light axigluon (Axi200x where x=L,R,A)

$m_G = 200\text{GeV} \qquad \Gamma_G = 50\text{GeV} \qquad \Delta A_{t\bar{t}} = 0.12$

(L) $\quad g_{R,i} = 0,\ g_{L,i} = 0.8\, g_s\ :\quad \Delta A_l = -0.07,$

(R) $\quad g_{R,i} = 0.8\, g_s,\ g_{L,i} = 0\ :\quad \Delta A_l = 0.18,$

(A) $\quad g_{R,i} = 0.4\, g_s,\ g_{L,i} = -0.4 g_s\ :\quad \Delta A_l = 0.05,$

Heavy axigluon (Axi1500x where x=L,R,A)

$m_G = 1.5\text{TeV} \qquad \Delta A_{t\bar{t}} = 0.12$

(L) $\quad g_{L,q} = -1.3\, g_s,\ g_{R,q} = 0,\ g_{L,t} = 6\, g_s,\ g_{R,t} = 0\ :\ \Delta A_l = -0.01,\ \Gamma_G = 970\ \text{GeV}$

(R) $\quad g_{L,q} = 0,\ g_{R,q} = -1.1 g_s,\ g_{L,t} = 0,\ g_{R,t} = 6 g_s :\ \Delta A_l = 0.14,\ \Gamma_G = 460\ \text{GeV}$

(A) $\quad g_{L,q} = 0.6\, g_s,\ g_{R,q} = -0.6\, g_s,\ g_{L,t} = -3\, g_s,\ g_{R,t} = 3\, g_s :\ \Delta A_l = 0.06,\ \Gamma_G = 350\ \text{GeV}$

Axi1500L and Axi1500R are in tension with LHC and Tevatron measurements of the high invariant mass t-tbar production; Axi200L and Axi200R are in tension with total t-tbar cross section at Tevatron; tension can be released by reducing couplings at the price of smaller top asymmetry

Lepton vs Top Asymmetry: pT(lepton) dependence

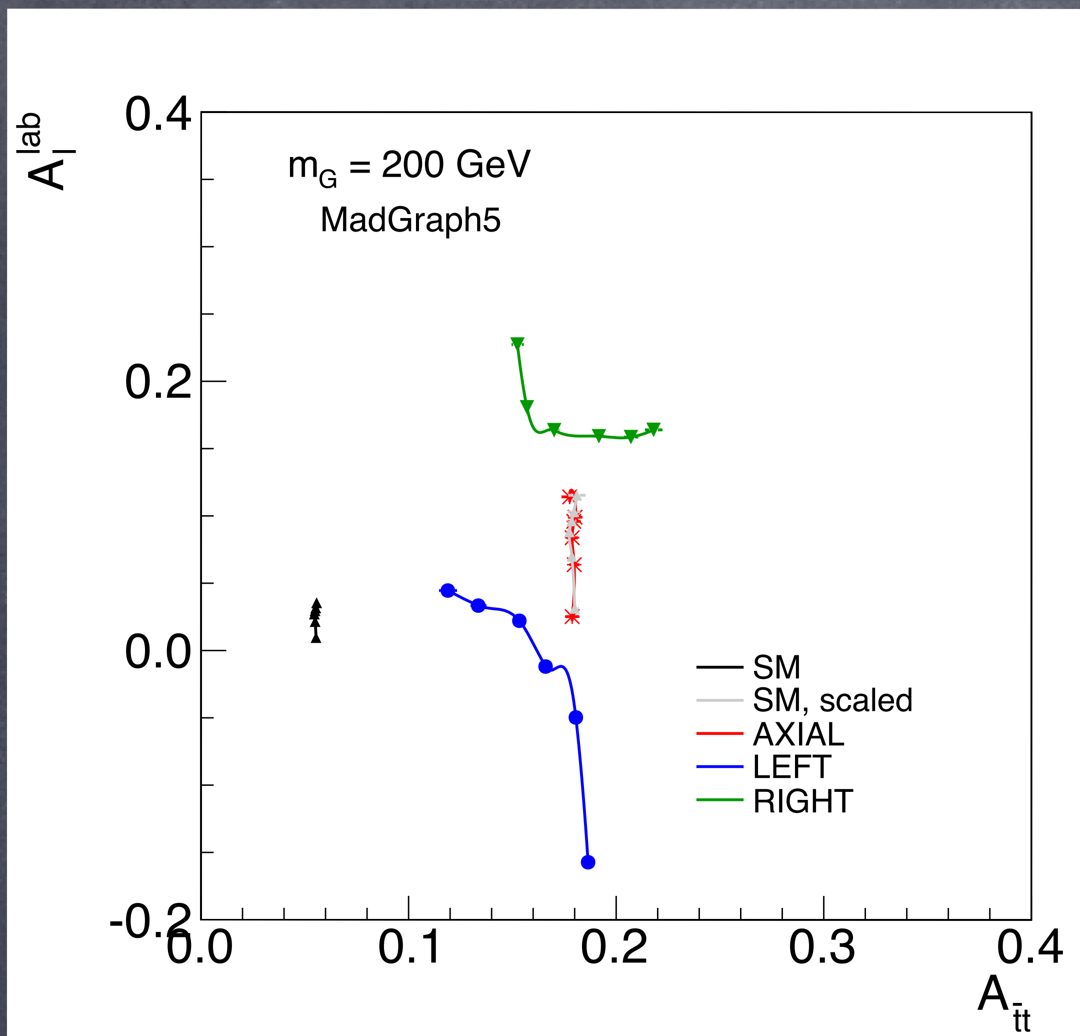
BSM physics may affect pT(l) distributions of asymmetries in 3 ways:

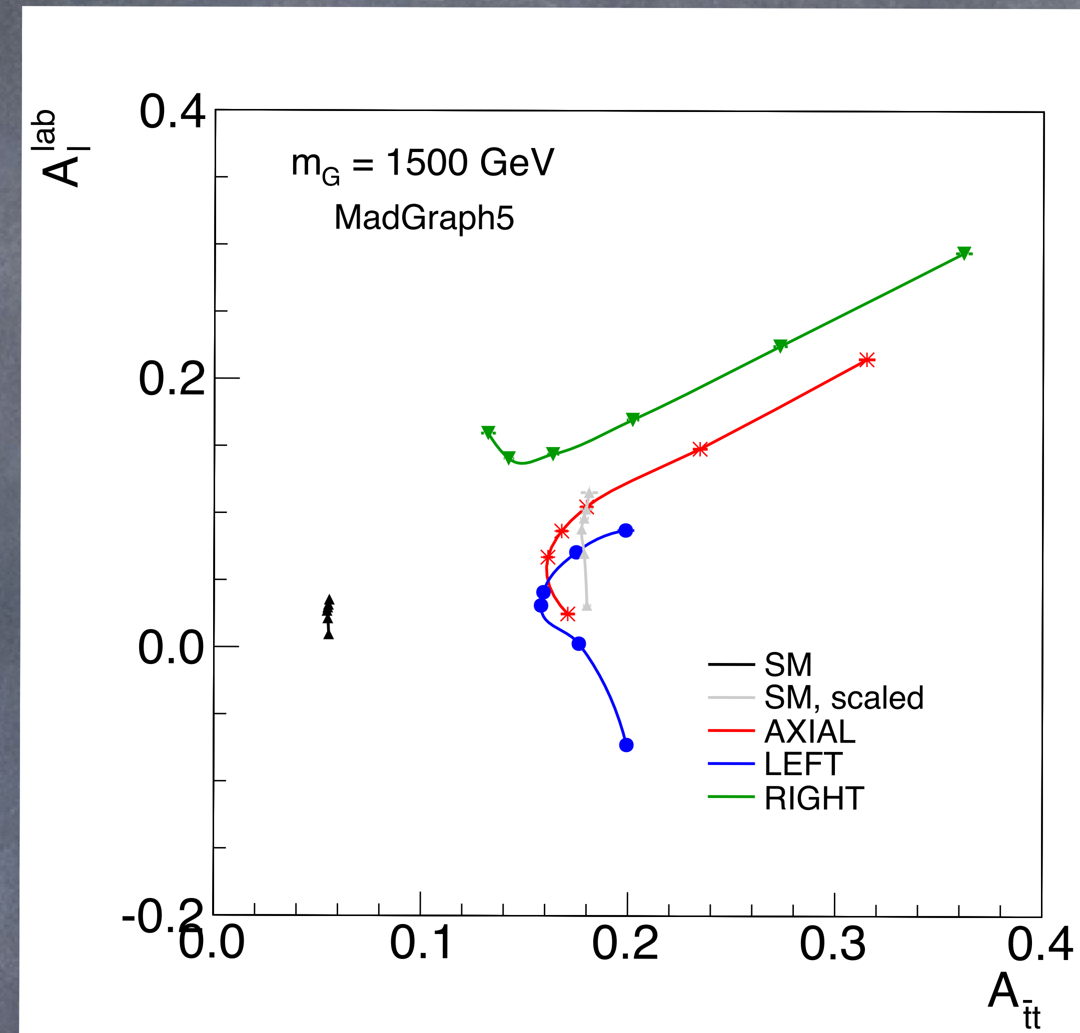
- 1) **Mttbar dependence.** Dependence of asymmetries on t-tbar invariant mass is typically different in BSM models, and then pT(l) dependence is also affected due to correlation between mtt and pT(l)
- 2) **Initial state polarization.** Different contribution of left- and right-handed quarks to t-tbar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

Lepton vs Top Asymmetry: pT(lepton) dependence

Example BSM benchmarks

AA, Mangano, Martin, Perez, Winter, [arXiv:1212.4003]





All benchmarks except Axi200A lead to distinctly different shape of pT(l) dependence in the A_{tt} - A_l plane

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-tbar threshold measures polarization of the light quarks that produce the t-tbar pairs
- Studying correlation of A_{tt} and A_l as function of other kinematic observables, in particular as function of pT(lepton), provides another test of the SM and additional discriminating power for new physics