Improving the Top Quark Afb Measurement at the LHC

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Introduction

- Tevatron measurements
  - CDF: $A_{FB}(M_{t\bar{t}} < 450 \text{ GeV}) = -0.116 \pm 0.153$
    $A_{FB}(M_{t\bar{t}} \geq 450 \text{ GeV}) = 0.475 \pm 0.114$
  - D0: $(19.6 \pm 6.5)\%$
- Models
  - S-channel: axigluon
  - t(u)-channel, flavor changing: Z-prime, W-prime, diquark, etc.

Confirm at the LHC?

Difficulties at the LHC

- proton-proton machine
  - valence quark *v.s.* sea quark: charge asymmetry

$$A_C = \frac{N(\Delta > 0) - N(\Delta < 0)}{N(\Delta > 0) + N(\Delta < 0)} \qquad \Delta = |y_t| - |y_{\bar{t}}|$$

CMS: $A_C^\eta = -0.016 \pm 0.030\ (\text{stat.})^{+0.010}_{-0.019}(\text{syst.})$

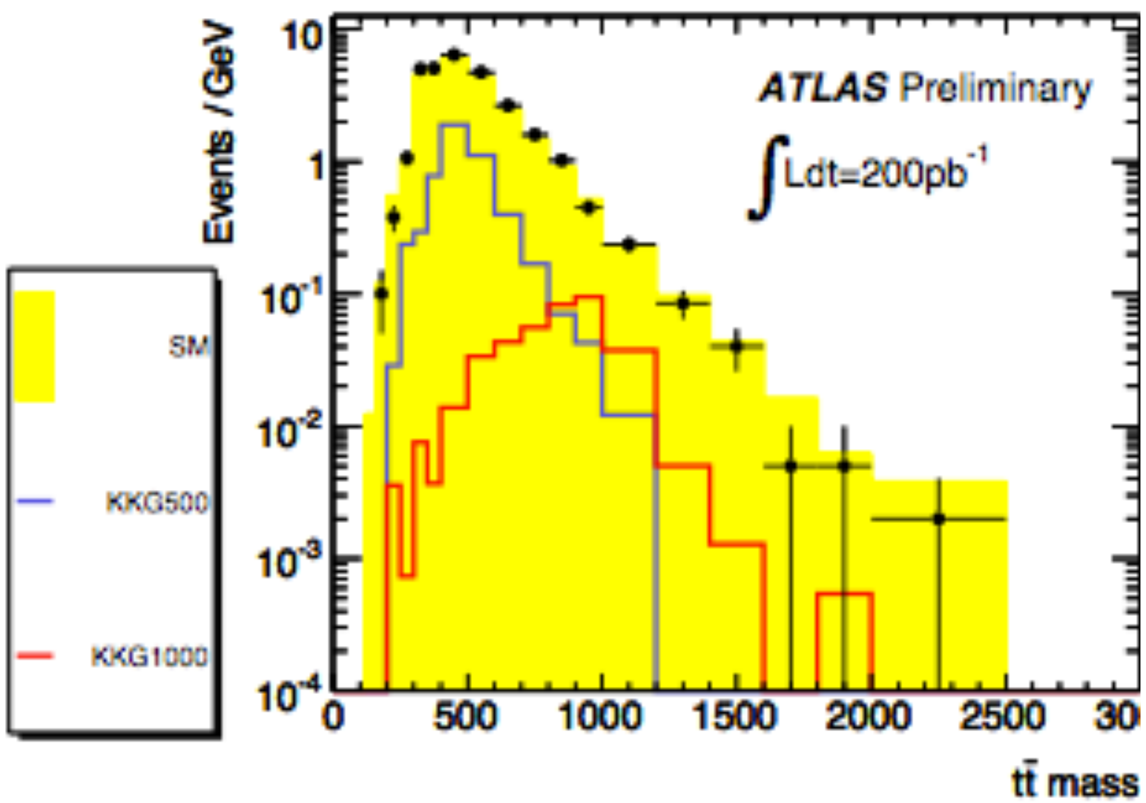
SM: $A_C^\eta = 0.013 \pm 0.001$

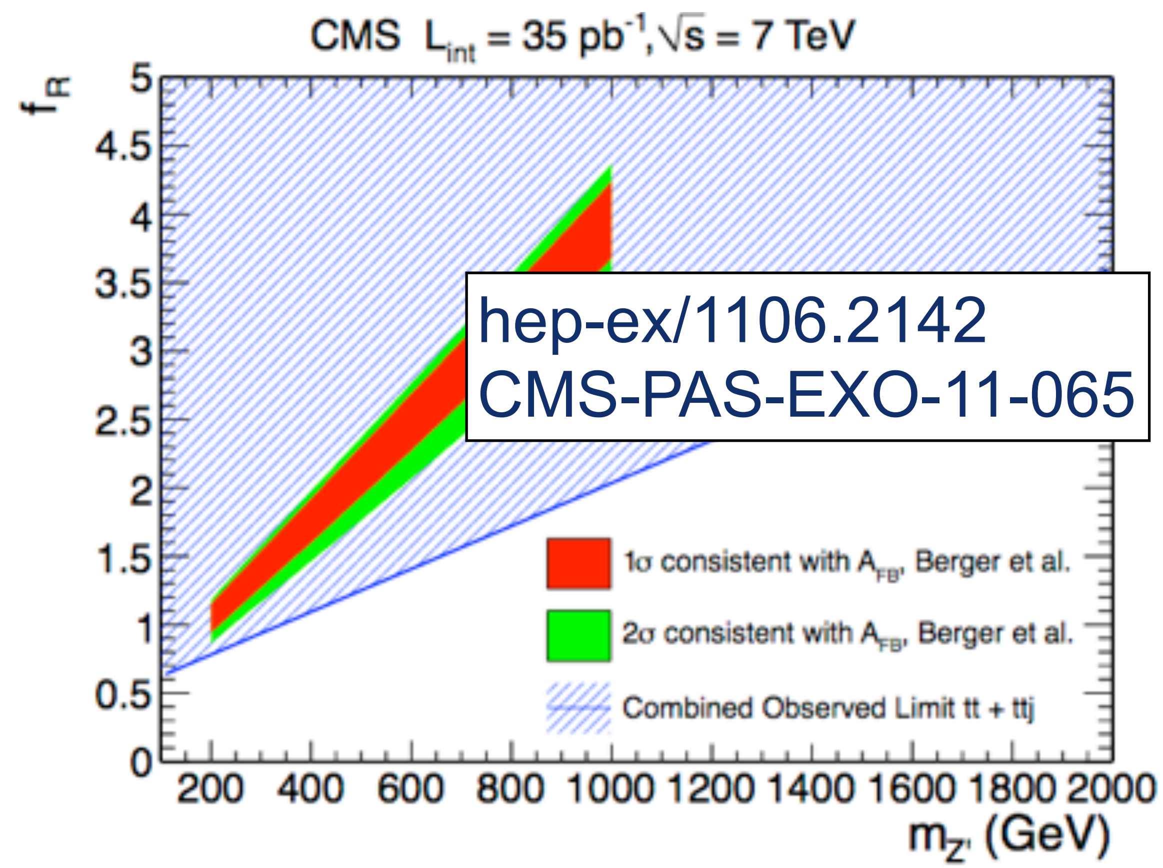
- gg->ttbar dominates, ~80%

How to reduce the gg component?

Constraints

- ttbar invariant mass
- same sign tops





New physics may not be so easy to discover

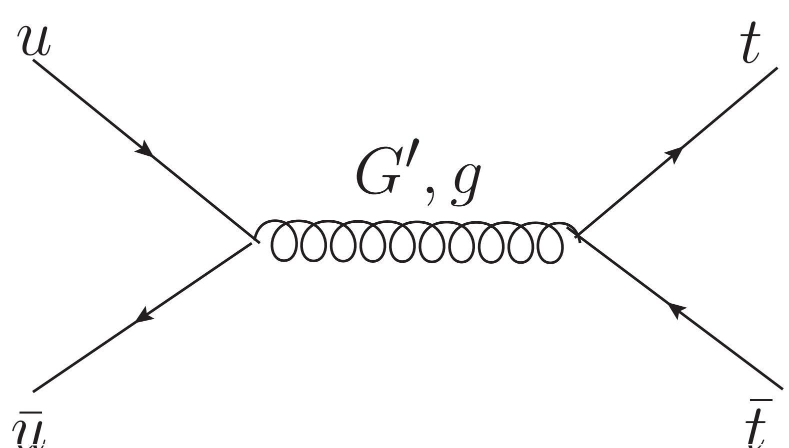
Outline

- Example models
- Variables distinguishing gg from qqbar
  - Simple kinematic variables
  - Polarization and spin correlation variables
- Combined improvements
- Discussion and Conclusion

Example models

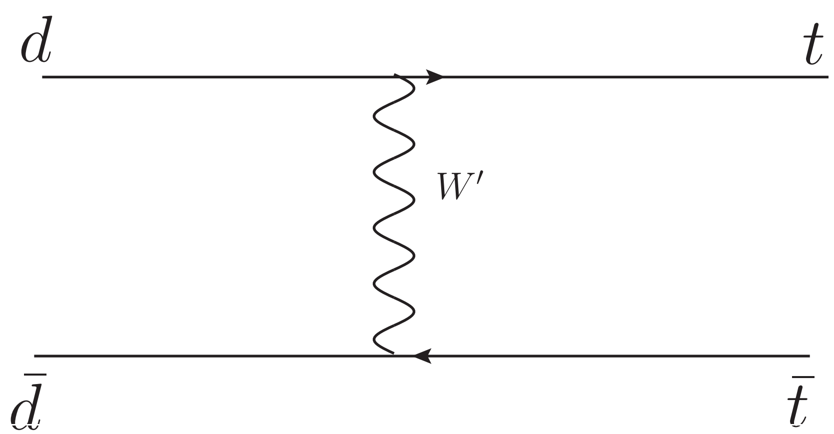
- S-channel model: axigluon G-prime

$$\mathcal{L}_{G'} \;=\; -G'^{\,a}_{\mu}\,\left[\bar{u}\,(g^q_V\gamma^\mu t^a + g^q_A\gamma^\mu\gamma^5 t^a)u \,+\, \bar{t}\,(g^t_V\gamma^\mu t^a + g^t_A\gamma^\mu\gamma^5 t^a)t\right] + \cdots$$



- T-channel model: W-prime

$$\mathcal{L}_{W'} \;=\; -W'^{+}_{\mu}\,\bar{t}(g_V\gamma^\mu + g_A\gamma^\mu\gamma^5)d \,+\, h.c. + \cdots$$



Example models

- Model A: G-prime with

$$M_{G'} = 2.0 \text{ TeV}, \; g_A^q = 2.2, \; g_A^t = -3.2, \; g_V^t = 1.0 \text{ and } g_V^q = 0.$$

- Model B: W-prime with

$$M_{W'} = 400 \text{ GeV and } g_V = g_A = 0.9 \text{ (or } g_L = 0 \text{ and } g_R = 1.8)$$

- Model C: effective 4-fermion operator

$$\xi \, \bar{u}\gamma_\mu \gamma^5 t^a u \, \bar{t}\gamma^\mu \gamma_5 t^a t / \Lambda^2$$

$$\xi = -1 \text{ and } \Lambda \equiv M_{G'}/(g_A^q g_A^t)^{1/2} = 650 \text{ GeV}$$

for M(ttbar)>450GeV, Afb at Tevatron: 0.31, 0.52, 0.53

LHC measurement

- 7TeV 3 inverse fb, assuming 10% efficiency, semileptonic channel

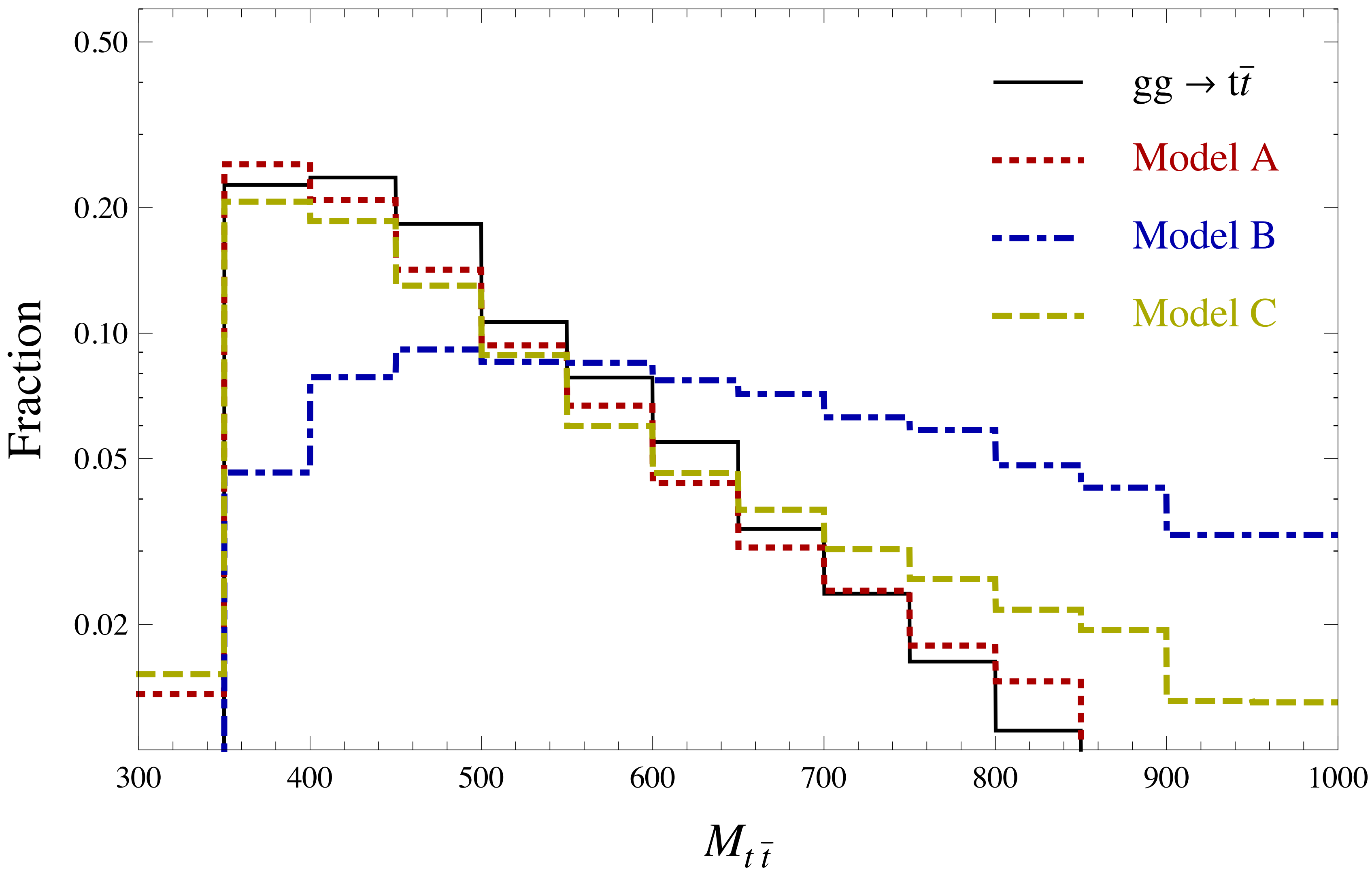
$$\text{Model A:} \qquad A_{FB}(M_{t\bar{t}} > 450 \text{ GeV}) = 0.046 \pm 0.015$$

$$\text{Model B:} \qquad A_{FB}(M_{t\bar{t}} > 450 \text{ GeV}) = 0.196 \pm 0.011$$

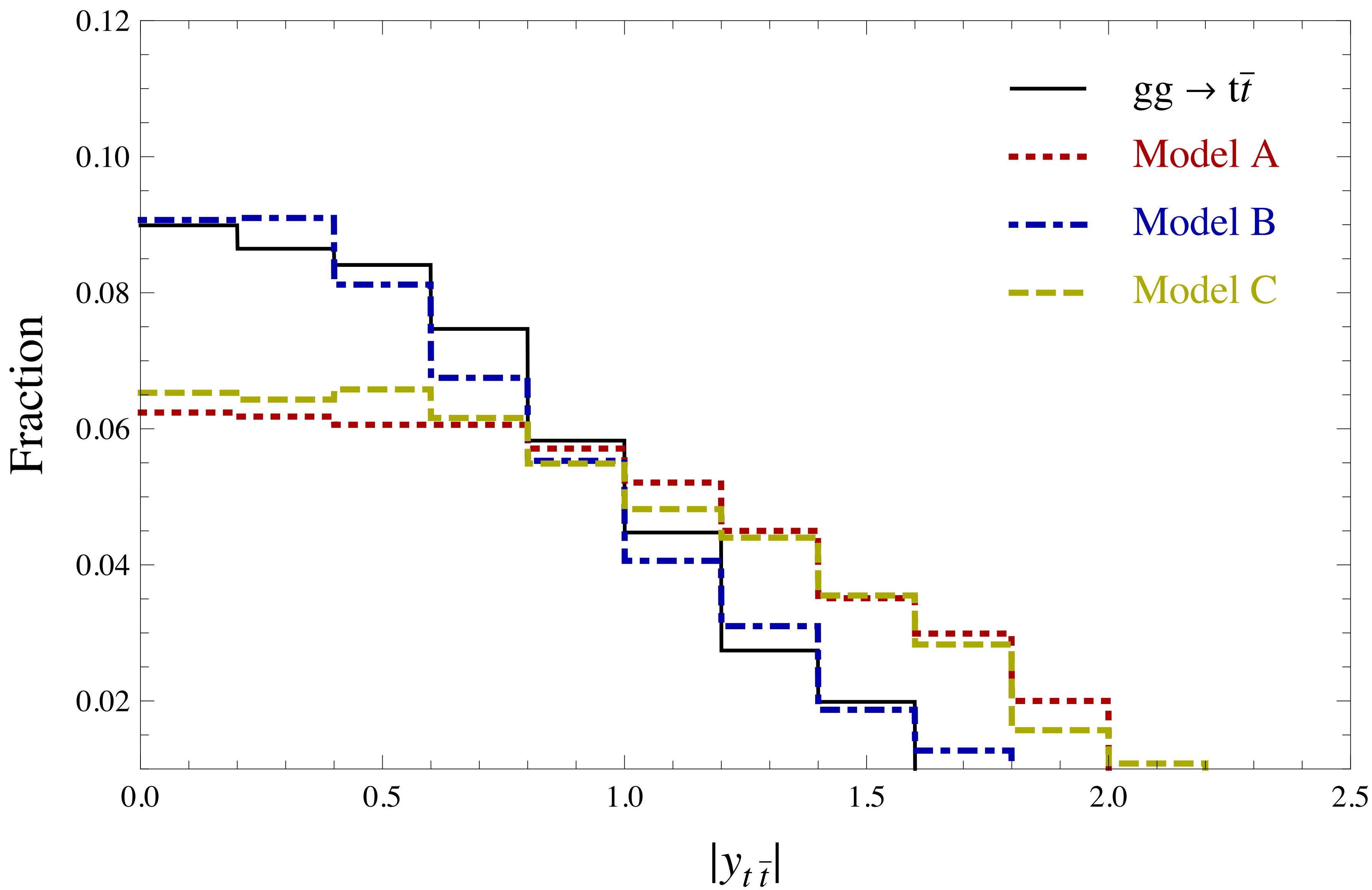
$$\text{Model C:} \qquad A_{FB}(M_{t\bar{t}} > 450 \text{ GeV}) = 0.099 \pm 0.015$$

- for comparison, model B with reduced coupling: gR=1.5, Afb=0.113 +- 0.013

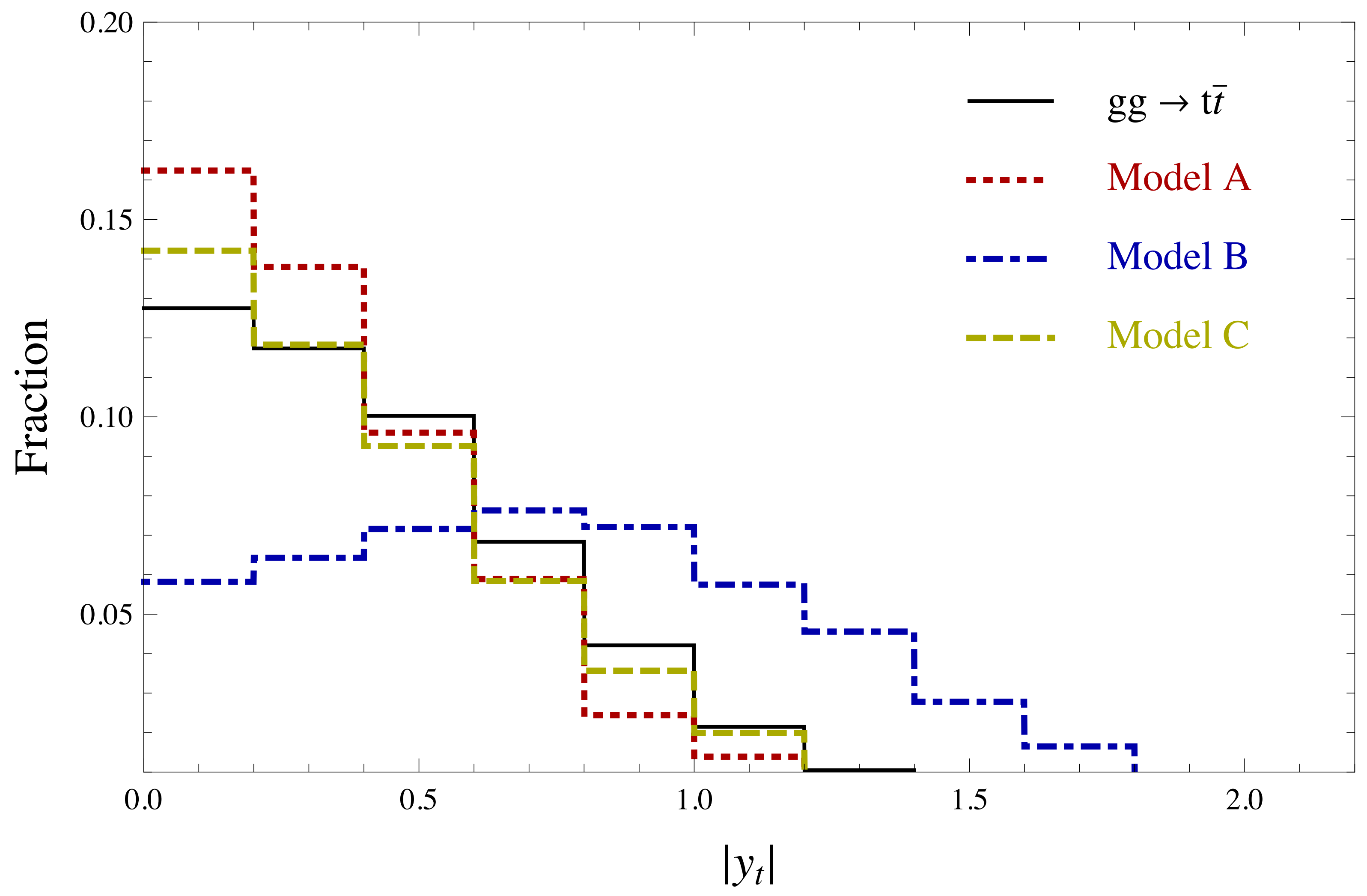
Kinematics--invariant mass



Kinematics--boost of ttbar



Kinematics--production angle

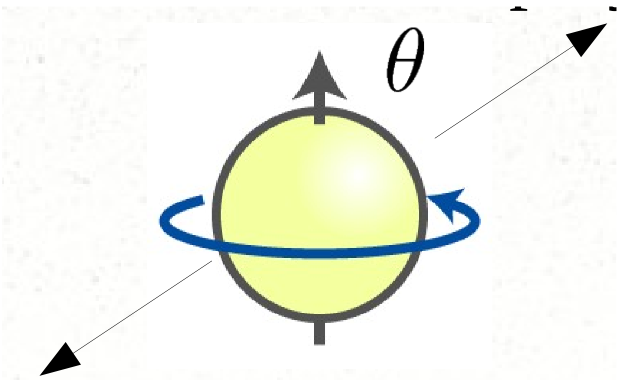


Polarization and spin correlation

- Lessons from the standard model:
  - Top from QCD is not polarized
  - Spin correlation different for gg and qqbar
  - Best axis for spin correlation: qqbar->ttbar 100% correlated in the off-diagonal basis *(Mahlon&Parke, 1997)*

Top polarization

- Model A, B (chiral couplings): top is polarized
- Model C (pure axial couplings): top not polarized
- How to observe the polarization?



$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_i} = \frac{1}{2}(1 + k_i\ \cos\theta_i)$$

θ_i: Angle between decay product i and the top polarization axis

$$k_{\ell^+} = k_{\bar{d}} = k_{\bar{s}} = 1,\ k_{\nu_\ell} = k_u = k_c = -0.31,\ k_b = -k_{W^+} = -0.41$$

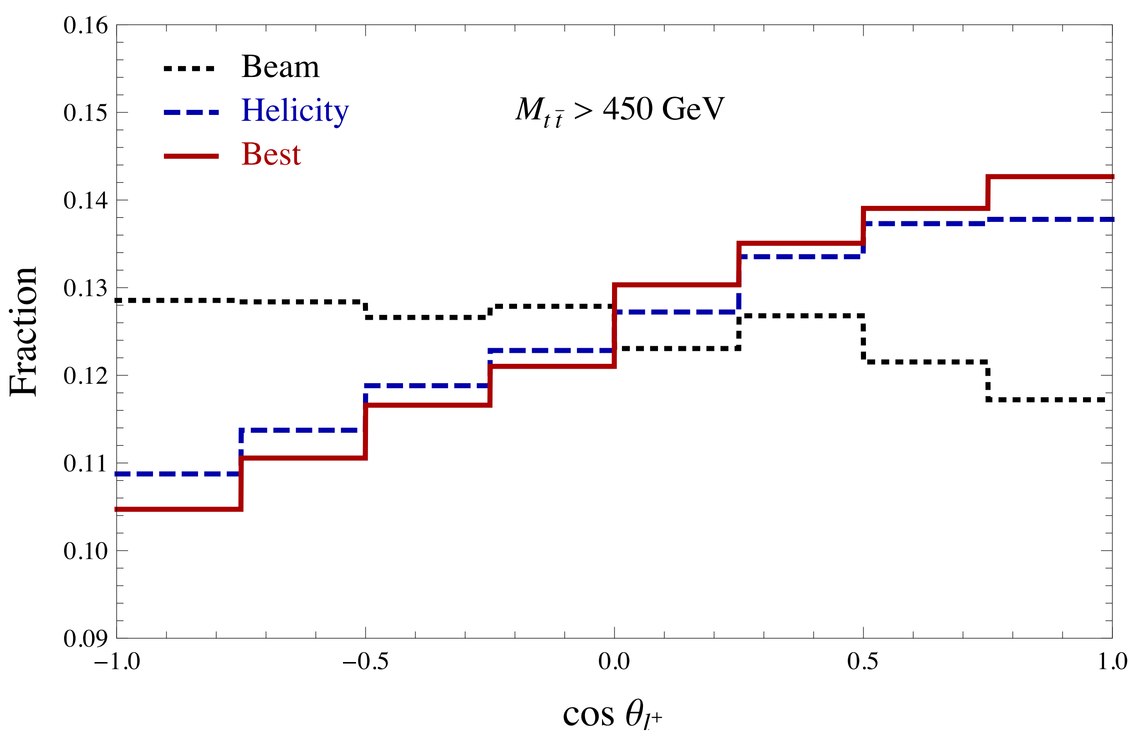
Best axis for polarization

- top polarization direction:

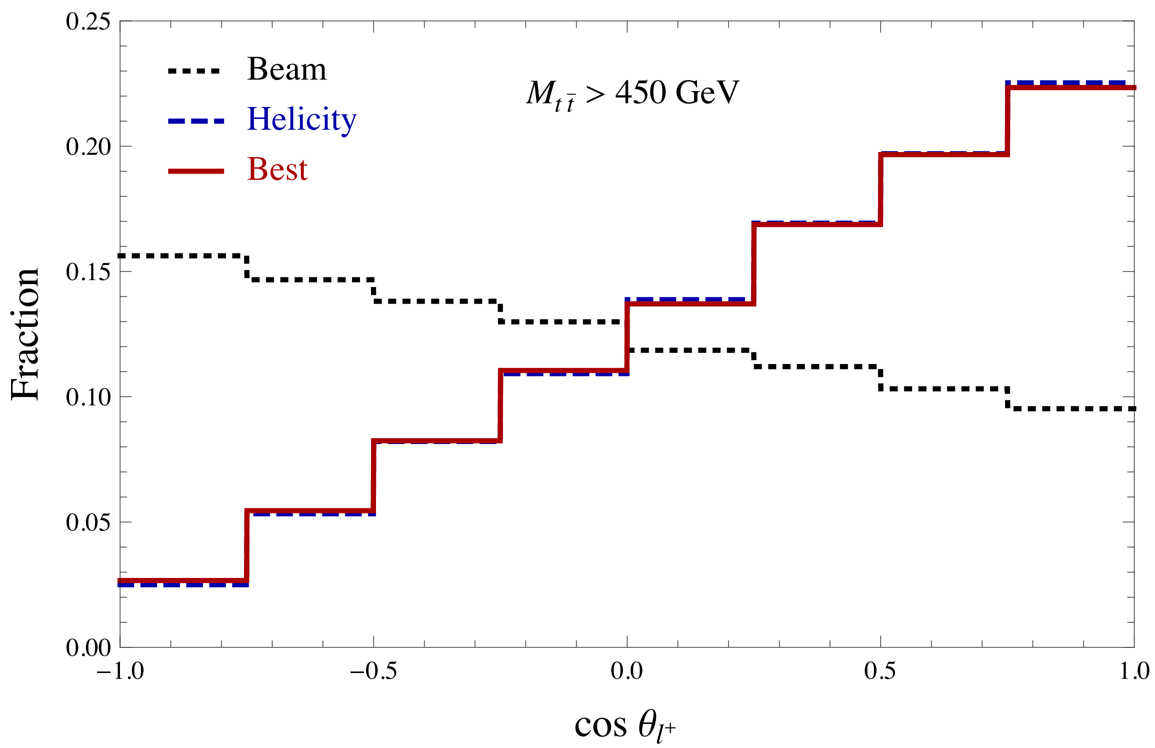
$$\mathbf{B}_t = b_t^{\hat{p}}\,\hat{\mathbf{p}} + b_t^{\hat{k}}\,\hat{\mathbf{k}}$$

$$\hat{\mathbf{k}} = (0, s_{\theta^*}, c_{\theta^*})^T \quad \hat{\mathbf{p}} = (0, 0, \pm 1)^T$$

- Direction is model dependent



Model A



Model B

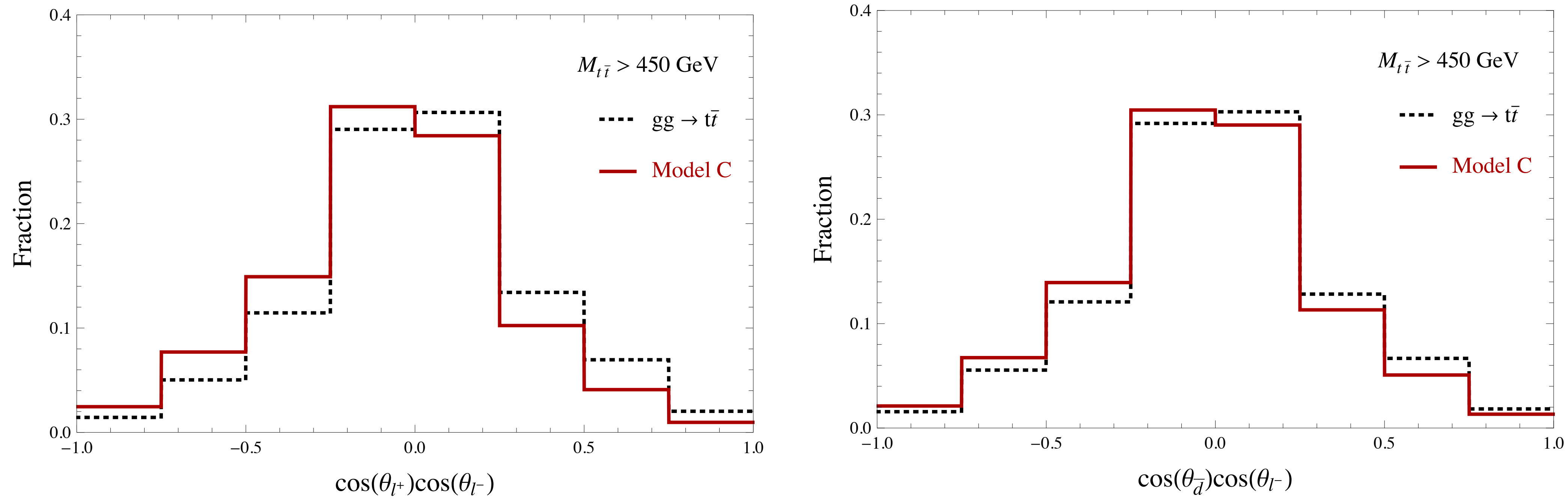
Top-antitop spin correlation

- Top and anti-top's spins are correlated

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_i\, d\cos\theta_j} = \frac{1}{4}(1 - \mathcal{C}\, k_i k_j\ \cos\theta_i\ \cos\theta_j)$$

- SM C=1 for qqbar->ttbar using the best axis
- Similar for axigluon with pure axial couplings: can identify the best axis with C=1

Top-antitop spin correlation



- Changed to a single variable

$$\frac{1}{N}\frac{dN}{d[\cos\theta_i \cos\theta_j]} = \frac{1}{2}(\mathcal{C}\, k_i k_j\ \cos\theta_i \cos\theta_j - 1)\log(|\cos\theta_i \cos\theta_j|)$$

- Dilepton channel, smaller branching ratio, event reconstruction more difficult; larger correlation

- Semileptonic channel: identify the jet closer to the b-jet in the W rest frame as 'down' quark (60% to be correct).

Use the variables

- Distinguish models
- Reduce gg background

Likelihood discriminant

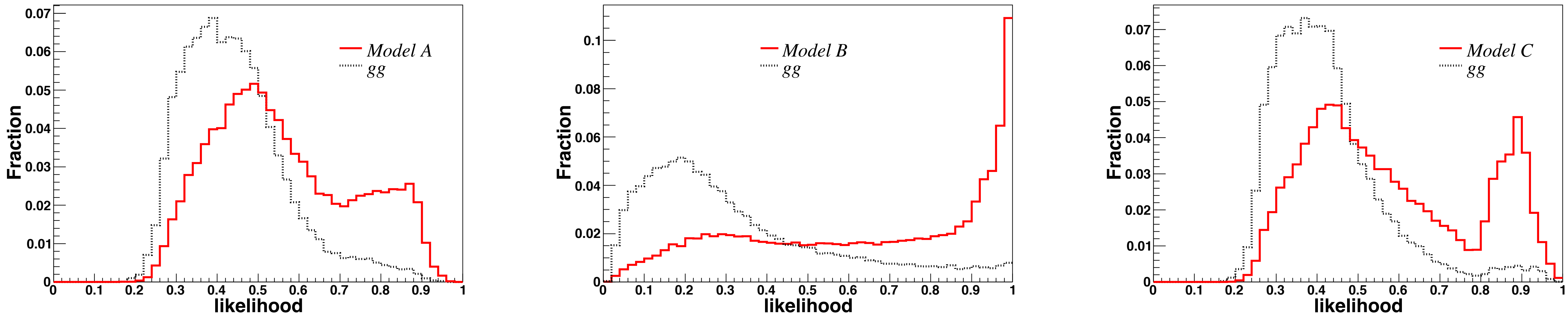
- Aim at increasing the significance, $A_{FB}/\sigma_{A_{FB}}$
- No improvement using any single variable--need to combine variables.
- For one variable, use same binning for simulated signal (qqbar->ttbar) and background (gg->ttbar), Normalize to the same area. Define probability

$$p_s^i(x^i) = \frac{s_j^i}{s_j^i + b_j^i}$$

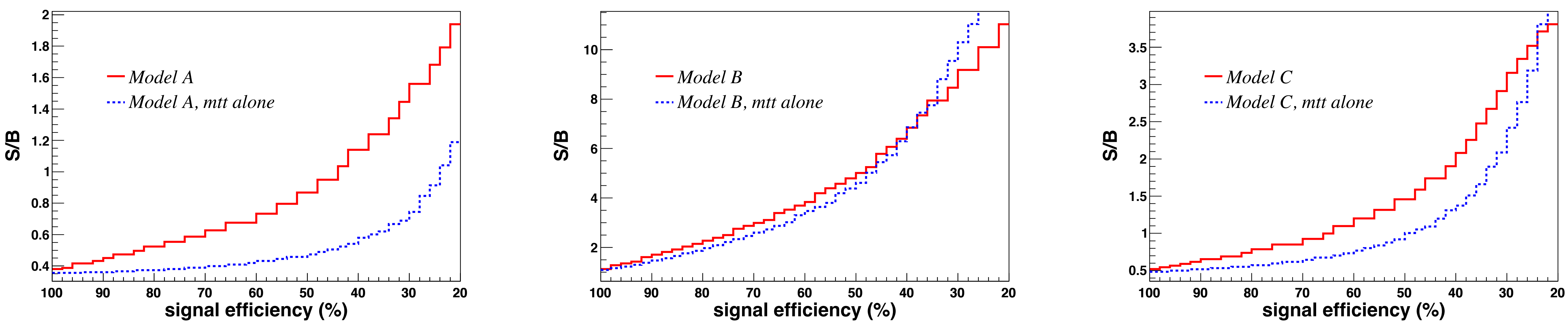
- Multivariable likelihood:

$$\mathcal{L}_s = \frac{\Pi_i p_s^i}{\Pi_i p_s^i + \Pi_i (1 - p_s^i)}$$

Cut on likelihood



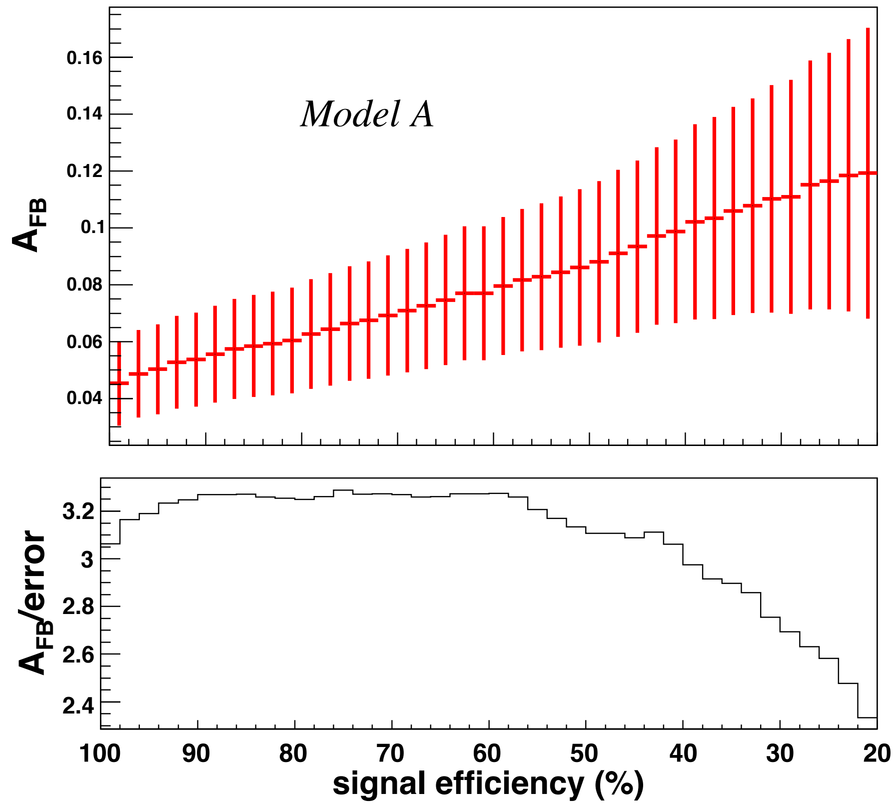
Likelihood

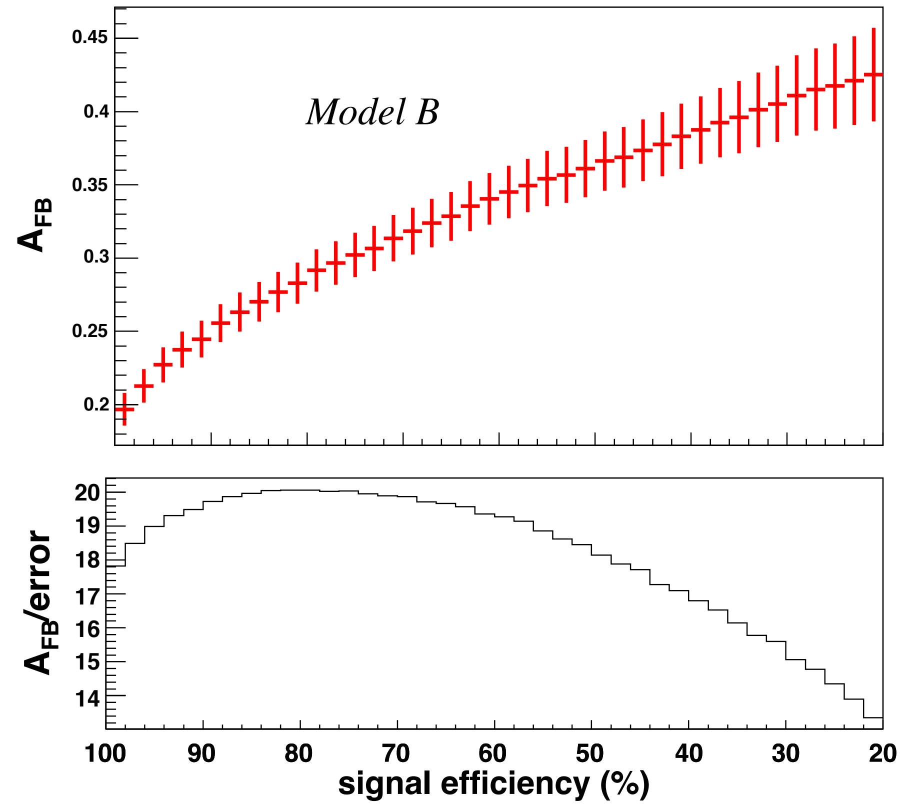


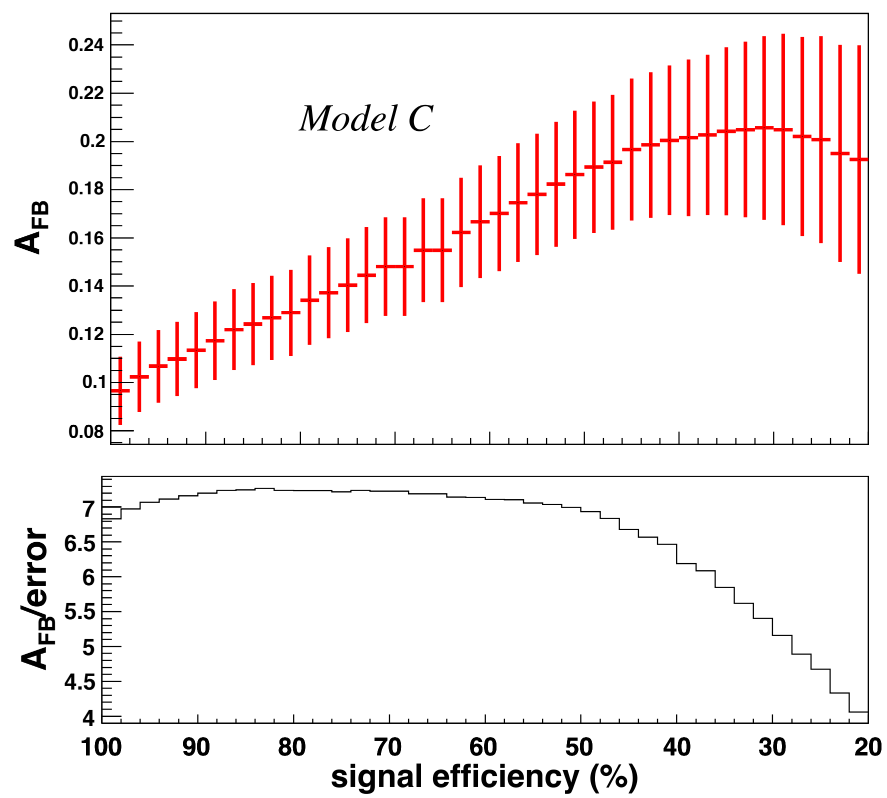
S/B

Afb Improvement

Central value & significance $A_{FB}/\sigma_{A_{FB}}$







Best significance:

Model A: $A_{FB}(\mathcal{L}_S > 0.49) = 0.078 \pm 0.024\,,$

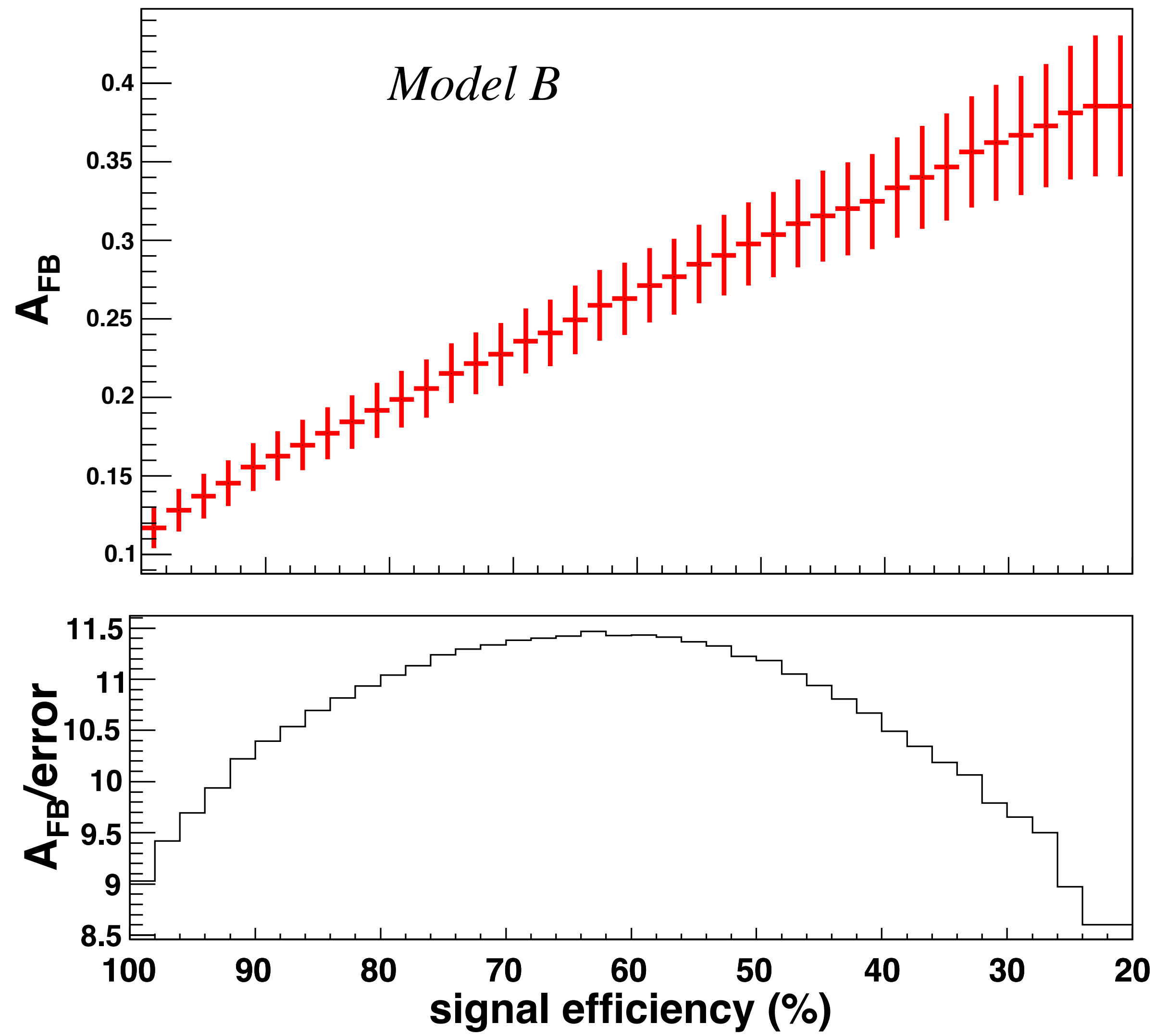
Model B: $A_{FB}(\mathcal{L}_S > 0.33) = 0.289 \pm 0.014\,,$

Model C: $A_{FB}(\mathcal{L}_S > 0.36) = 0.121 \pm 0.017\,.$

Significance increase by ~10%, central value 20-70%

Improvement

- Model B with smaller coupling (1.5)
- Best Afb=0.260+-0.024 (compare 0.113+-0.013)



Discussion

- Model dependence
  - Not many models have survived/will survive
  - Different models share similar feature, for example, Z-prime and W-prime similar enhancement in the forward region
  - Simplified approach?
- Detector resolution, reconstruction....

Conclusion

- We have examined variables that can distinguish between ttbar events produced from gluons and those from qqbar at the LHC
- The best axes for studying top polarization and spin correlation are identified
- Combining the variables in a likelihood discriminant method increases the significance by 10-30%, and central value by 20-100% for typical models