1. Top Quark Forward-Backward Asymmetry, Same-sign Top Quark Pairs, Top Quark Polarization, and New Physics

Berger, Q-H Cao, C-R Chen, G Shaughnessy, and H Zhang

arXiv:1101.5625 (Phys Rev Lett 106, 201801 (2011))

arXiv:1005.2622 (Phys Rev Lett **105**,181802 (2010))

arXiv:1009.5379 (Phys Lett B **696** (2010) 68)

arXiv:1103.3274 (Phys Rev D, in press)

2. Higgs Boson Search Sensitivity at 7 TeV

Berger, Q-H Cao, C B Jackson, T Liu, and G Shaughnessy

arXiv:1003.3875 (Phys Rev D 82, 053003 (2010))

3. Double Parton Scattering at the LHC

Berger, C B Jackson, and G Shaughnessy

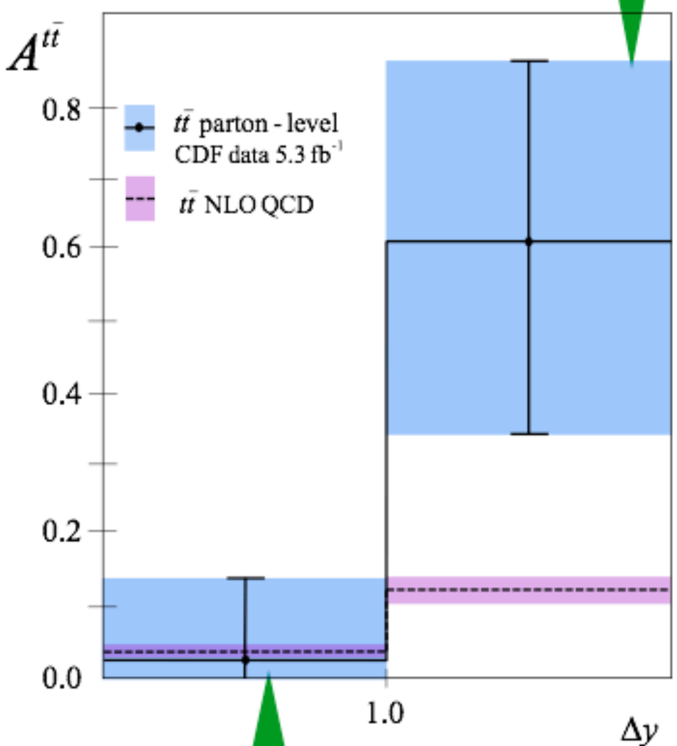
arXiv:0911.5348 (Phys Rev D 81, 014014 (2010))

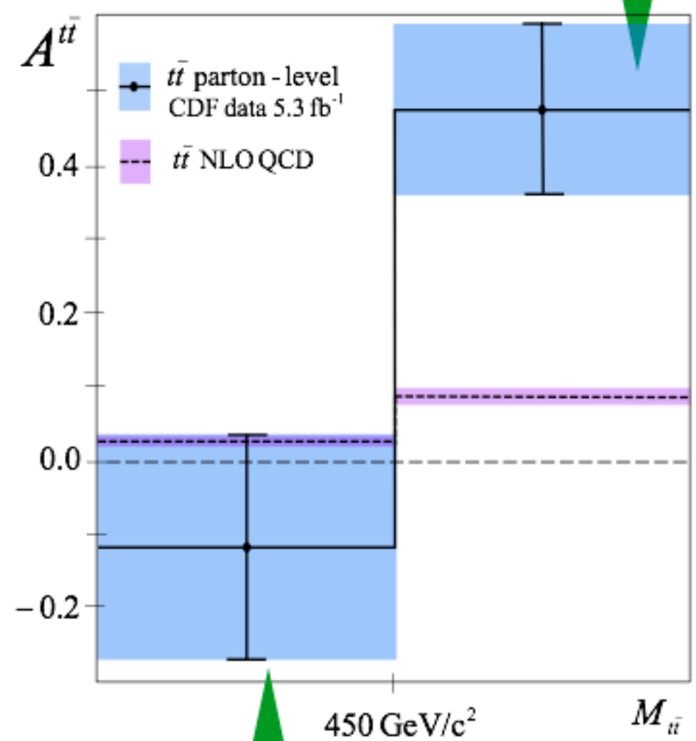
plus with S Quackenbush (draft written)

CDF measurement arXiv:1101.0034 5.3 fb^{-1}

$$A_{FB}^{\mathrm{obs}} = 0.611 \pm 0.256$$
$$A_{FB}^{\mathrm{SM}} = 0.123 \pm 0.018$$

$$A_{FB}^{\mathrm{obs}} = 0.475 \pm 0.112$$
$$A_{FB}^{\mathrm{SM}} = 0.088 \pm 0.013$$



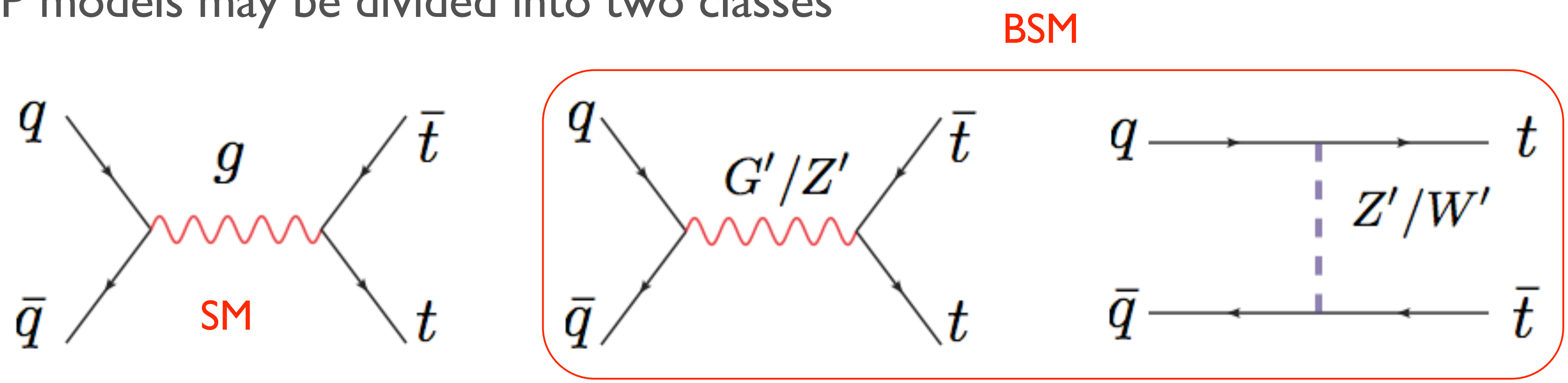


$$A_{FB}^{\mathrm{obs}} = 0.026 \pm 0.118$$
$$A_{FB}^{\mathrm{SM}} = 0.039 \pm 0.006$$

$$A_{FB}^{\mathrm{obs}} = -0.116 \pm 0.153$$
$$A_{FB}^{\mathrm{SM}} = 0.040 \pm 0.006$$

New physics models

★ NP models may be divided into two classes



s-channel: extra octet vector gluon (axigluon, …..?)

small couplings to the first two generations: dijet constraints at 7 TeV
large couplings to third generation: to generate large A_{FB}
heavy resonances: ttbar invariant mass spectrum constraints
broad width: to interfere with the SM amplitude

t-channel: flavor changing interaction

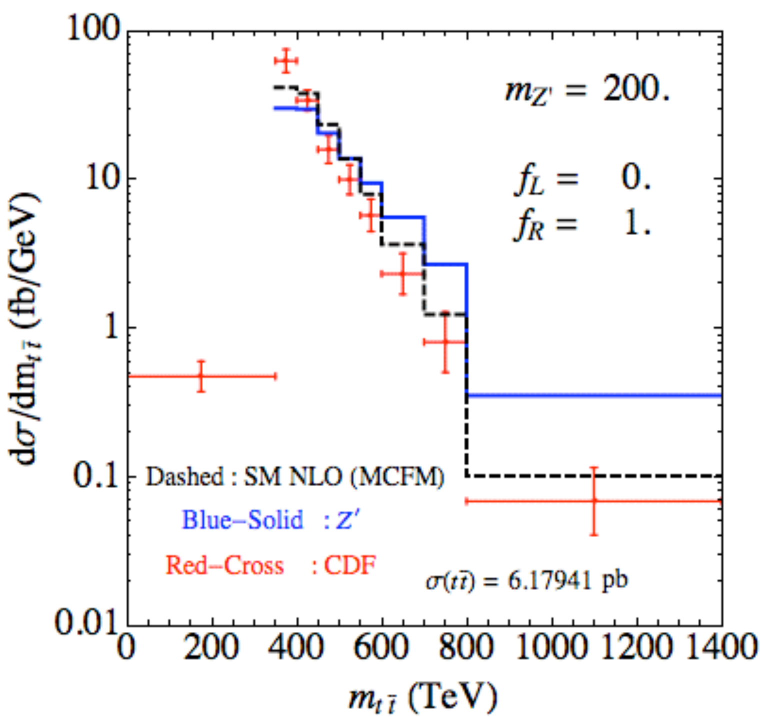
color singlet: $Z' - u - t$ (ϕ-u-t) color sextet or triplet
$W'^{+} - d - t$ (ϕ^{+}-d-t)

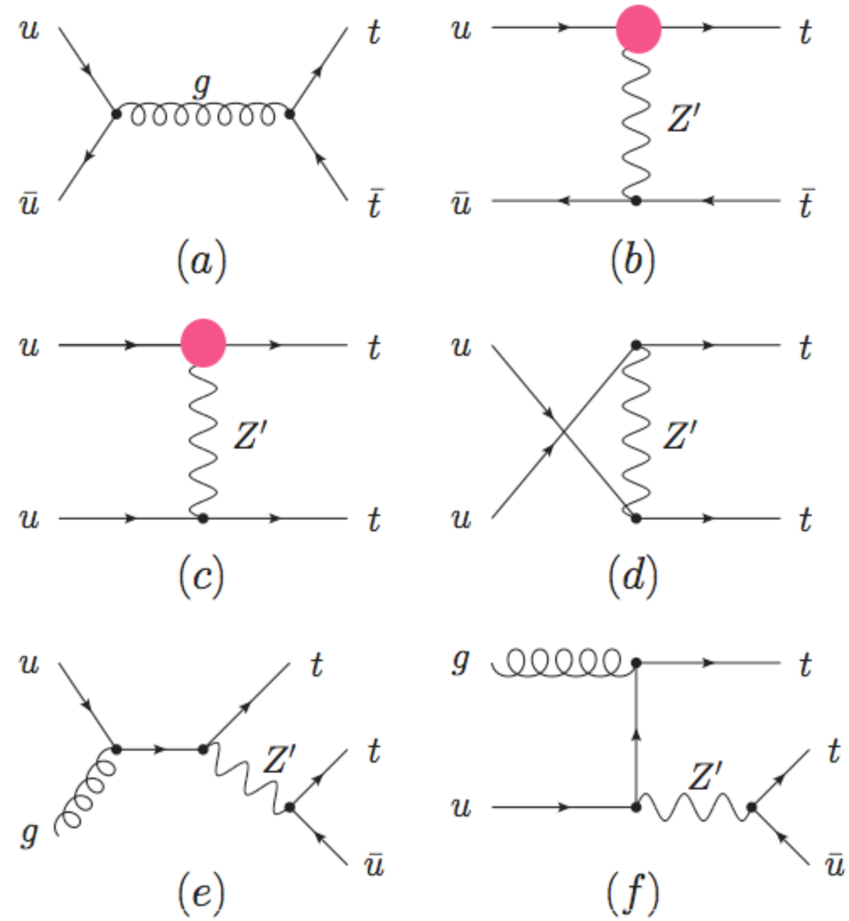
What can one say about the FCNC Z' model at 7 TeV (or at the Tevatron)?

FCNC Z-prime model

$$\mathcal{L} = g_W \bar{u}\gamma^\mu (f_L P_L + f_R P_R) t Z'_\mu + h.c.$$

Left-handed coupling is highly constrained by $B_d - \bar{B}_d$ mixing.





A large right-handed FCNC coupling f_R is needed to explain A_{FB} data.

Tevatron Constraints

★ Fit to the Tevatron data includes SM, NP, and Interference terms.

★ The inclusive cross section for $t\bar{t}$ pair production has been measured accurately. Its agreement within errors with SM expectations limits f_R from above.

$$\sigma(t\bar{t}) = 7.50 \pm 0.48 \text{ pb}$$

★ The $t\bar{t}$ invariant mass spectrum, both normalization and shape, also imposes an upper bound on NP models.

★ Large A_{FB} observed for $m_{t\bar{t}} \geq 450 \text{ GeV}$ limits f_R from below.

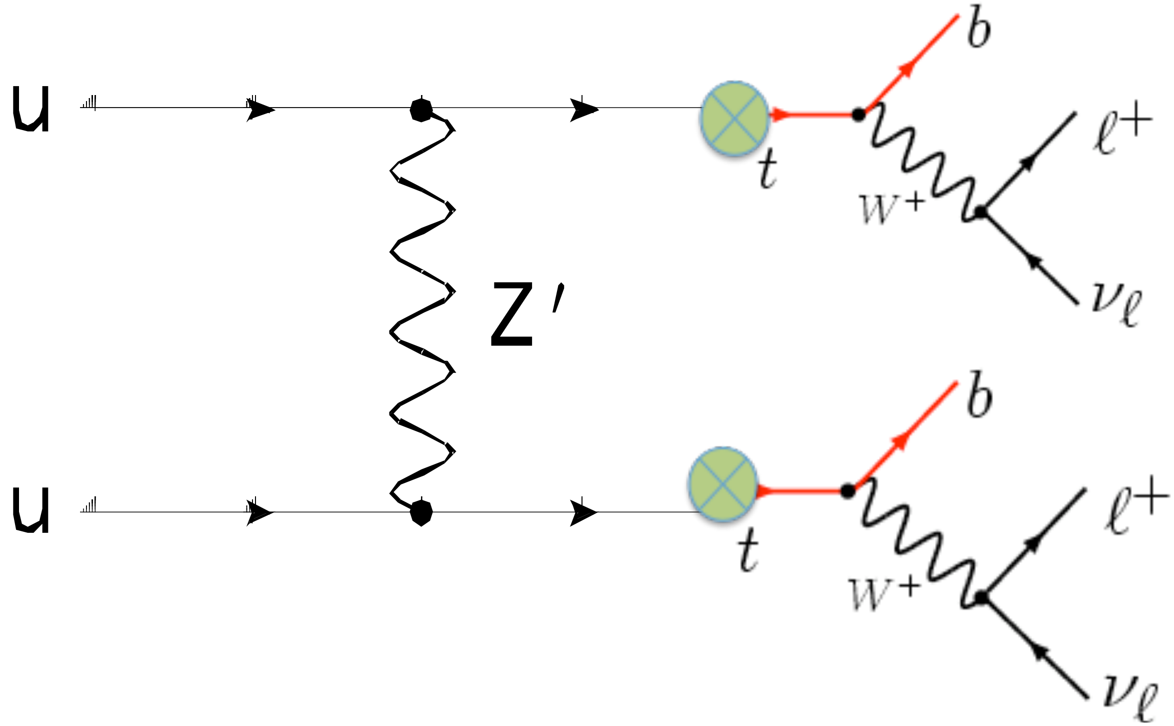
$$A_{\rm FB} = 0.475 \pm 0.114$$

★ The negative search for same-sign top quark pair at Tevatron also limits the NP parameter space.

$$\sigma(tt + \overline{tt}) < 0.7 \text{ pb}$$

FCNC Z-prime implications

★ Same-sign top quark pair production in u u scattering at the LHC

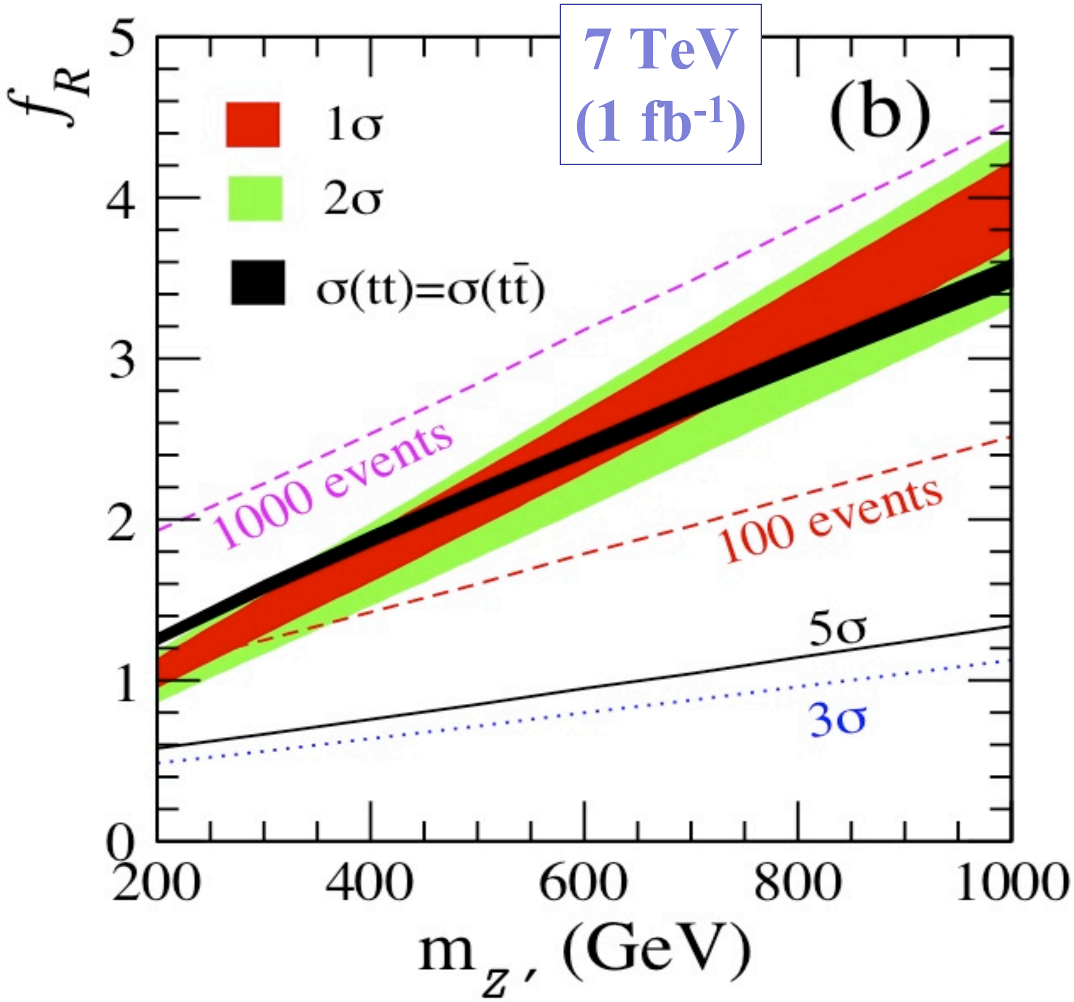


★ Same-sign dileptons are predicted.

★ The same sign top quark pair cross section grows as f_R^4 .

Same-sign top pair production

Flavor Changing Z' Model -- LHC Predictions



Parameter region of right-handed coupling f_R and Z' mass to fit Tevatron A_{FB} is above the LHC 5σ discovery curve.

Bands show the 1 σ and 2 σ fits to the $t\bar{t}$ inclusive cross section and A_{FB} .

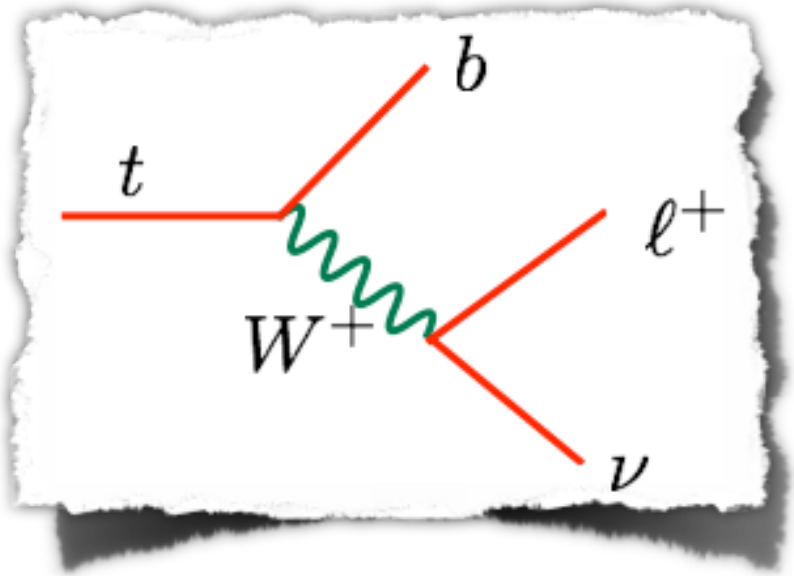
Z-prime exchange alone is an unlikely explanation of A_{FB}

LHC 7 TeV measurements would impose hard constraints on f_R . Search for same-sign top quark pairs is interesting in other model contexts also.

Top quark polarization is sensitive to NP

★ Top quark: the only "bare" quark one can measure in the Lab

★ Top quark spin info is retained in the
top quark decay products.



★ Polarization correlates with the angle between top quark spin and the charged lepton momentum:

$$\frac{1}{\Gamma}\frac{d\Gamma(t\to b\ell\nu)}{d\cos\theta}=\frac{1}{2}\left(1+\frac{N_+-N_-}{N_++N_-}\cos\theta\right)$$

✳ Charged lepton follows the top quark spin direction.

Top quark polarization

★ Polarization correlates with the angle between top quark spin and the charged lepton momentum:

$$\frac{1}{\Gamma}\frac{d\Gamma(t \to b\ell\nu)}{d\cos\theta} = \frac{1}{2}\left(1 + \frac{N_+ - N_-}{N_+ + N_-}\cos\theta\right)$$

✳ Charged lepton follows the top quark spin direction.

✳ In the FCNC Z-prime model, the right-handed top quark yields

$$\frac{1}{2}(1 + \cos\theta)$$

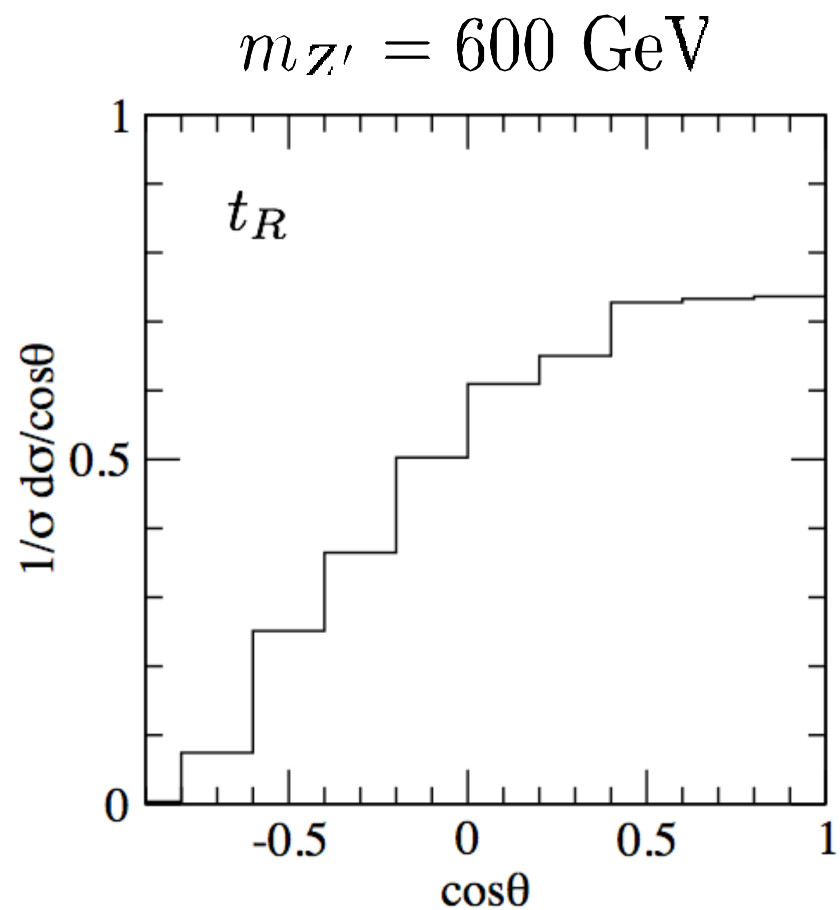


Figure shows the results of a full simulation, with cuts

Summary: Tevatron A_{FB} data and LHC Test

★ Among NP explanations of the top quark A_{FB} data, the FCNC Z-prime is attractive as it explains the large asymmetry found at large $t\bar{t}$ invariant mass and in the forward region

★ Fit Tevatron A_{FB} and the $t\bar{t}$ inclusive cross section to extract coupling f_R

★ FCNC interaction leads to same-sign top quark pair production at the LHC and the Tevatron. Could be detected easily at 7 TeV. Our code is being used by CMS and by ATLAS; results soon

★ CMS and ATLAS data on the $t\bar{t}$ pair production cross section (single lepton and dilepton comparison) already impose a limit on the same-sign/opposite sign ratio and, therefore, on FCNC couplings

★ FCNC Z-prime model alone cannot explain the A_{FB} data

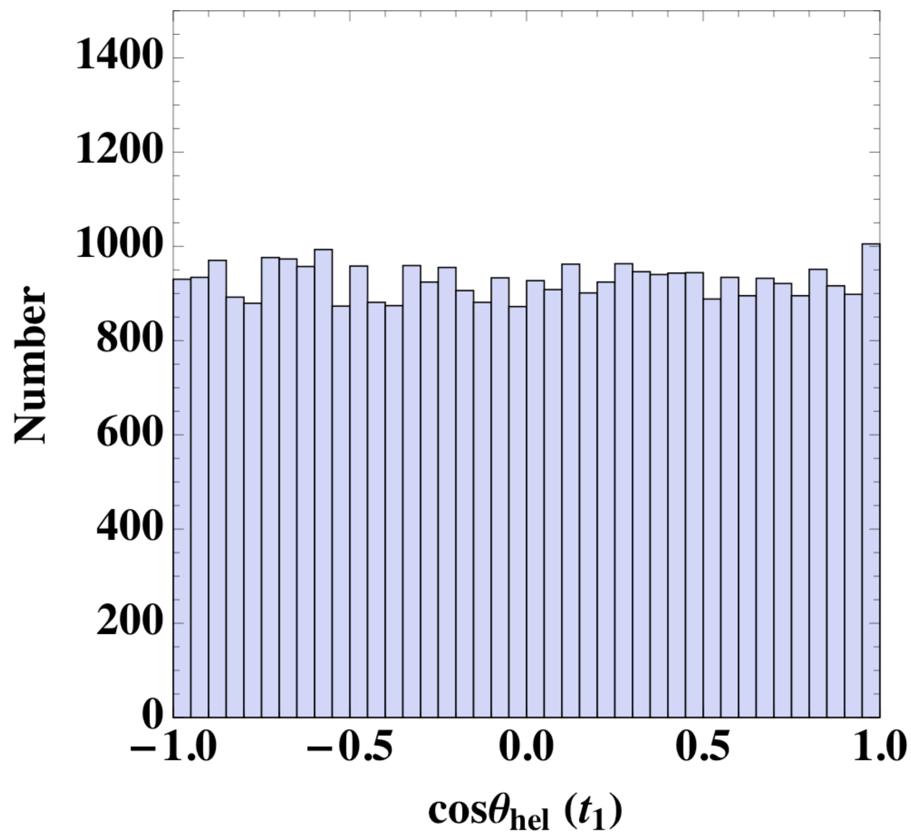
★ Polarization measurement is important and doable

Color sextet vectors and same-sign t t Pairs

H Zhang, E L Berger, Q-H Cao, C-R Chen, and G Shaughnessy
arXiv:1009.5379 (Phys Lett B **696** (2010) 68)

★ Top quarks are oppositely polarized, but the net polarization distribution of the two identical top quarks exhibits a flat profile (i.e. like unpolarized top quarks).

★ Despite the flat profile for sextet vectors, we can still determine that the top quarks have L and R polarizations by exploiting asymmetric lepton momentum cuts.



Lepton energy and top quark polarization

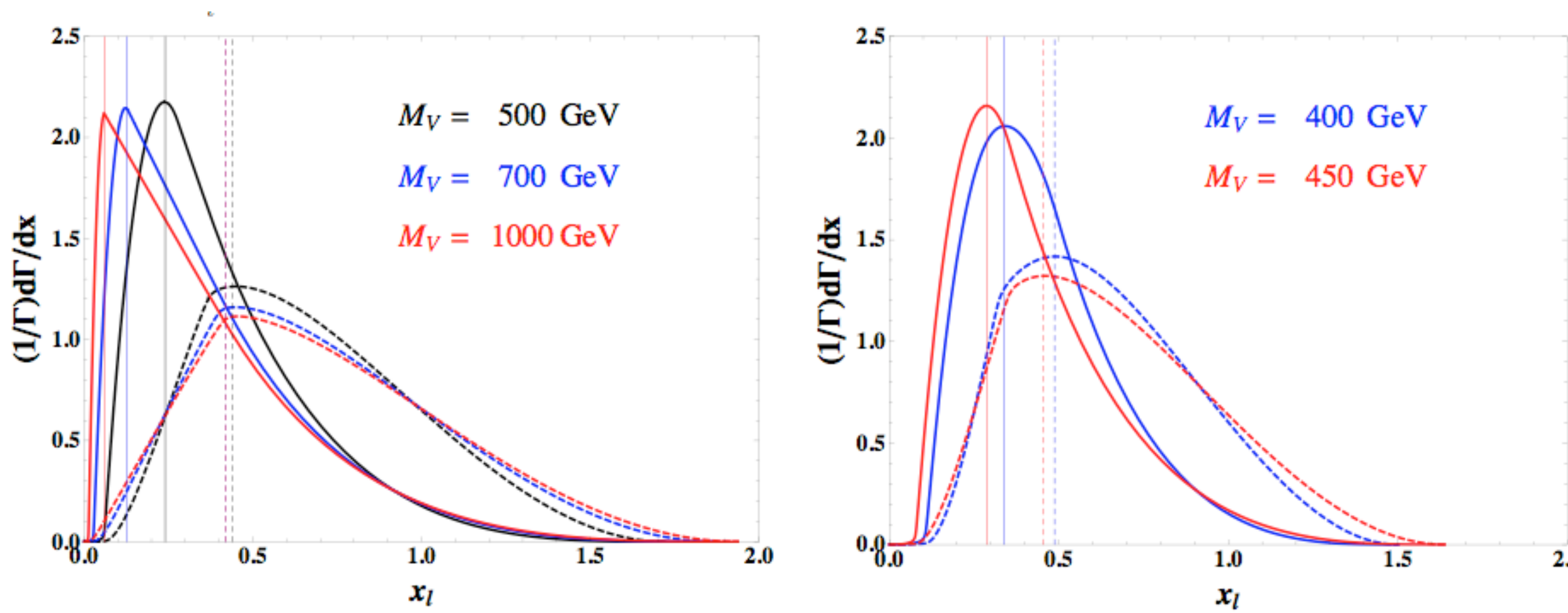
★ Peak positions are listed as follows:

EB, Q-H Cao, J. Yu and H. Zhang in preparation.

β value	left-handed top quark	right-handed top quark
$(0.91, 1)$	$-\frac{(1-\beta)^2}{1-3\beta} W\left[-\frac{1-3\beta}{1-\beta}\exp\left(-B+\ln B+\frac{2\beta}{1-\beta}\right)\right]$	$B(1+\beta)$
$(0.52, 0.91)$	$-\frac{(1-\beta)^2}{1-3\beta} W\left[-\frac{1-3\beta}{1-\beta}\exp\left(-B+\ln B+\frac{2\beta}{1-\beta}\right)\right]$	$-\frac{(1+\beta)^2}{(1+3\beta)} W\left[-\frac{(1+3\beta)}{(1+\beta)}\exp\left(-\frac{1+3\beta}{1+\beta}\right)\right]$
$(0, 0.52)$	$\frac{(1-\beta^2)}{2\beta}\left(1-\frac{1-\beta}{\beta}\text{arctanh}\beta\right)$	$-\frac{(1-\beta^2)}{2\beta}\left(1-\frac{1+\beta}{\beta}\text{arctanh}\beta\right)$

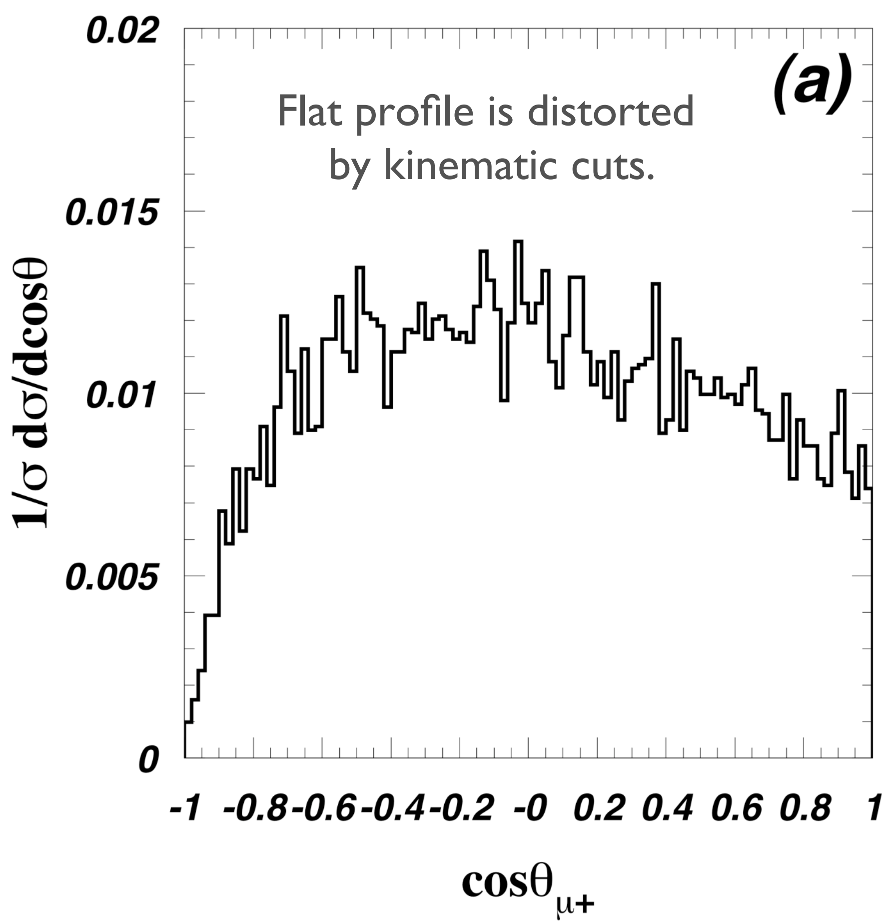
$B = \frac{m_W^2}{m_t^2}$

W is the Product Logarithm function

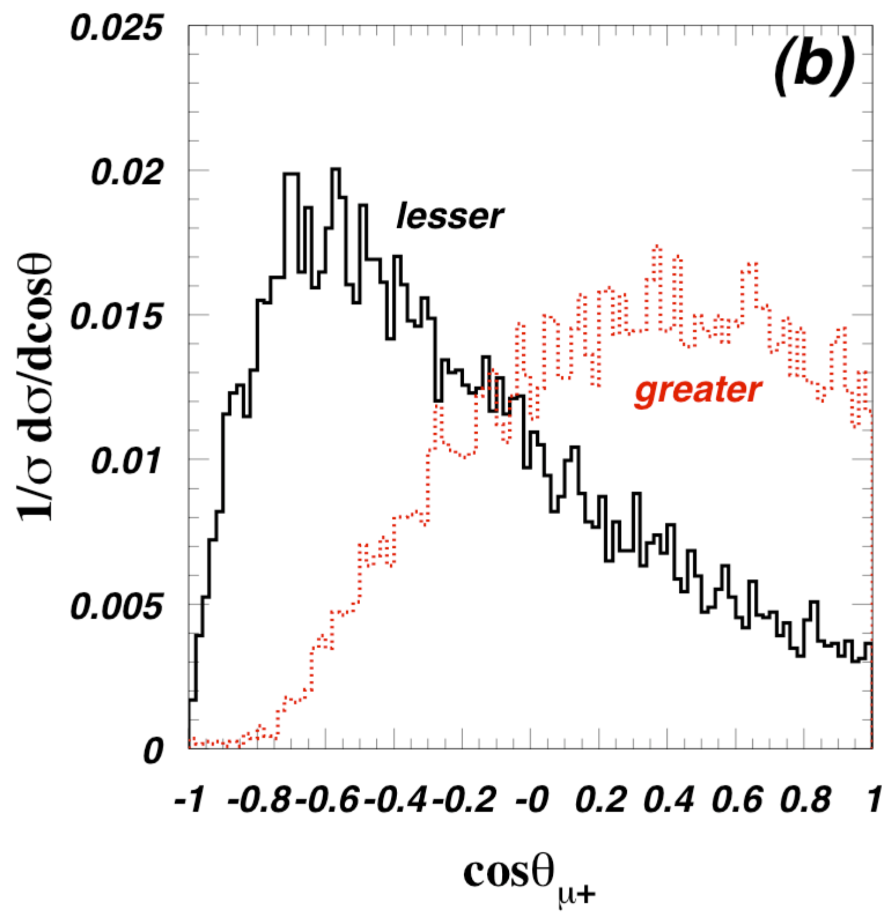


Sextet Vector Decay: Top quark polarization

★ Before lepton energy selection



★ After lepton energy selection



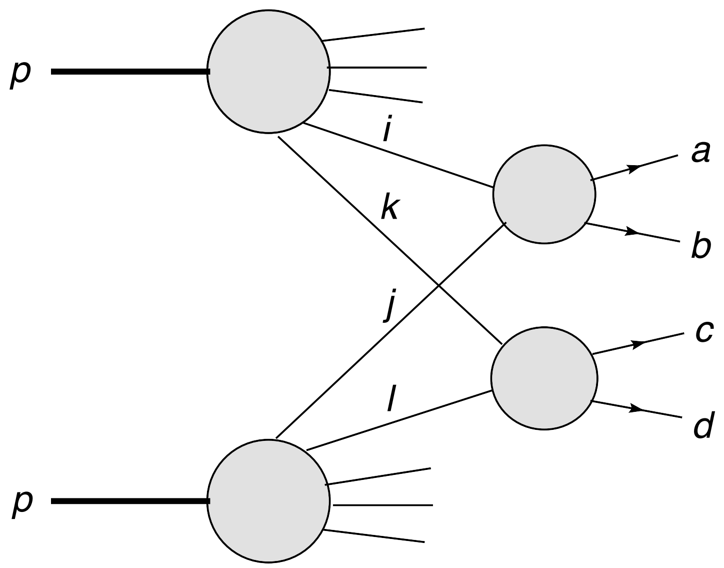
✳ Roughly 98 (67) events required to distinguish vector lesser (greater) from vector unpolarized case

3. Double Parton Scattering at the LHC

- Worked through $pp \to b\bar{b}jjX$ in detail, with C B Jackson and Gabe Shaughnessy, Phys Rev D 81, 014014 (2010)
  - Aim: identify signature kinematic variables and characteristic concentrations in phase space that distinguish DPS events from the usual single parton scattering SPS events
- Establish a methodology to measure the size of DPS
  - Once established in a well defined process, here, $pp \to b\bar{b}jjX$, then DPS contributions in other final states can be calculated; possibly important for background estimates in new physics searches
- Ongoing work – $pp \to Wb\bar{b}X$ with Seth Quackenbush

What is double parton scattering?

- Two hard collisions per pp interaction



- Assumed to exist and modeled in Monte Carlo codes for the "underlying event"
- Can we show that this second hard scattering is present in data as a discernable contribution?
- What are its characteristics, allowing its measurement?

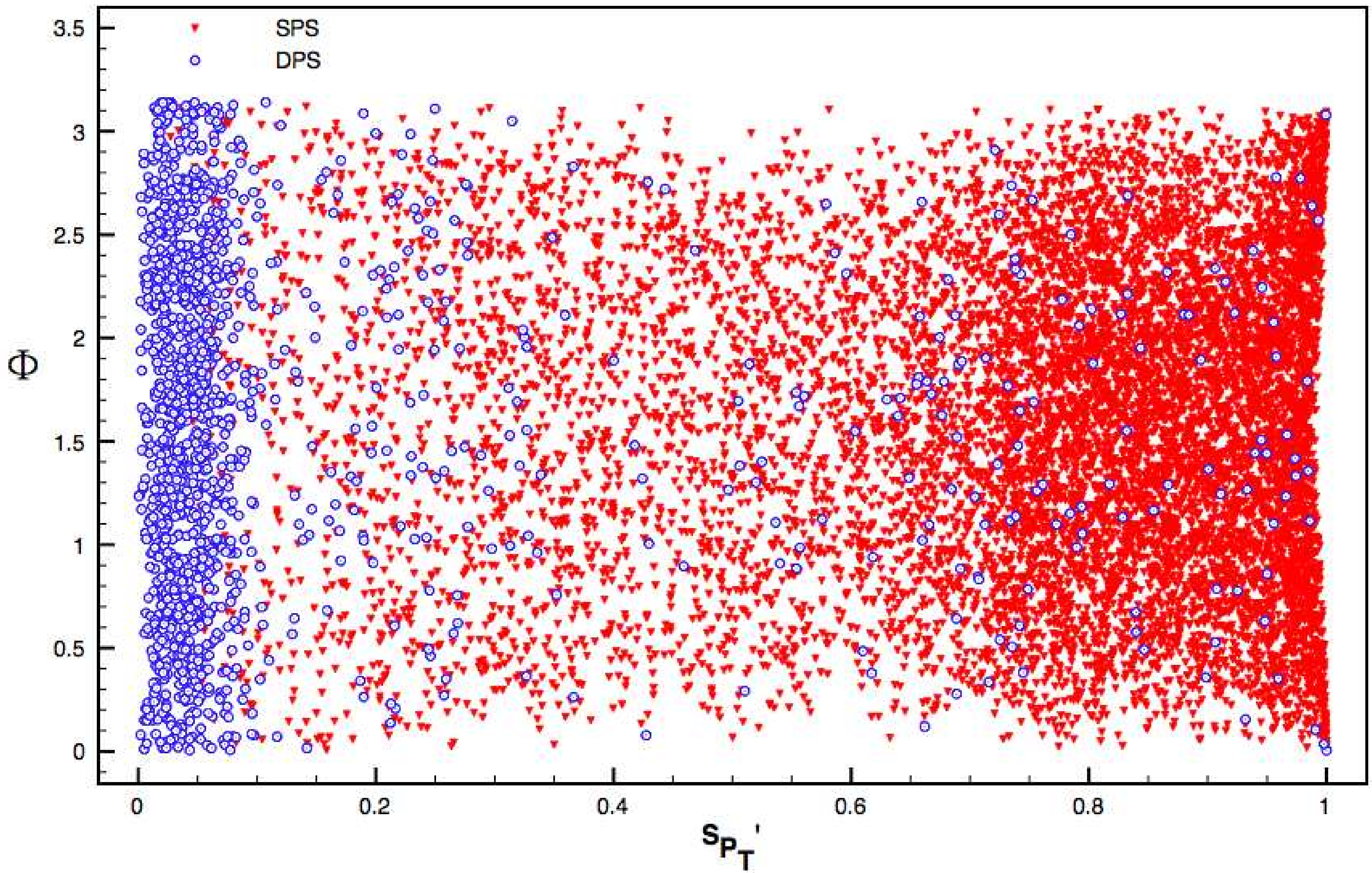
Two important distinguishing variables

- Φ: angle between the planes defined by $b\bar{b}$ and jj systems.
  Uncorrelated scatters: the DPS Φ distribution is flat. In SPS, $p+p \to b\bar{b}jjX$, many QCD diagrams contribute; spin and kinematic correlations are expected between the planes
- S'_{p_T} exploits back-to-back nature of the $2 \to 2$ subprocesses

$$S'_{p_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|p_T(b_1, b_2)|}{|p_T(b_1)| + |p_T(b_2)|}\right)^2 + \left(\frac{|p_T(j_1, j_2)|}{|p_T(j_1)| + |p_T(j_2)|}\right)^2}$$

DPS events produce a clear peak near $S'_{p_T} = 0$, well separated from the total. SPS events are away from back-to-back (gluon splitting)

Two-dimensional distribution



Clear separation of DPS from SPS in the 2-D Φ and S'_{p_T} plane

ATLAS and CMS are working on this analysis

Summary – Double Parton Scattering

- Developed the phenomenology of double parton scattering for $pp \to b\bar{b}jjX$ at LHC energies
- Identified distinct regions of phase space in which DPS should be relatively clean
- LHC operates in a different region of Bjorken x from the Tevatron: wider dynamic range provides opportunity to explore characteristics of DPS – factorization, process independence, ...
- Experiment Would be valuable to establish a DPS signal in early LHC runs and measure its effective cross section, $\sigma_{\rm eff}$
- Once $\sigma_{\rm eff}$ is measured in a clean process, and DPS features are established in a clean process (or two), then estimates can be made for possibly important backgrounds to Higgs and new physics processes

4. Other Publications and Future Plans

1. Other recent publications include
   - Parton distribution functions, with Pavel Nadolsky, Phys. Rev. D **82**, 114023 (2010) (arXiv:1010.4315 (hep-ph))
   - Isolated leptons from heavy flavor decays, with Zack Sullivan, Phys. Rev. D 82, 014001 (2010) (arXiv:1003.4997 (hep-ph))
2. Future: LHC results will have a significant influence, however they turn out
   - perturbative QCD for production processes; new physics signals and SM look-alikes
   - Higgs boson and BSM phenomenology
   - top quark physics; polarization tests
   - ....

5. Selected Other Recent Activities

1. Organizer (with Petriello, Soper, Webber, Zanderighi), Aspen Summer Workshop "Forefront QCD and LHC Discoveries" , May 23 to June 20, 2010.
2. Chair, Committee on Constitution and Bylaws, American Physical Society, 2011.
3. Search Committee, Senior Computational Scientists, Argonne National Laboratory, 2009 to present.
4. Co-Organizer, ATLAS LHC Physics Jamborees at Argonne.
    - May 2009 – S. Ellis, T. LeCompte, T. Tait, B. Mellado
    - November 2010 – D. Soper, J. Campbell, A. Siodmok (HERWIG++)
    - October 2011 – Boosted Objects
5. Scientific Program Organizing Committee, Rencontres de Moriond, QCD and High Energy Hadronic Interactions, La Thuile, Italy, March 2009, 2010, 2011.