26-30 March 2012
DIS 2012
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Hunting for New Physics in Top Pair Production

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29/03/2012, Bonn

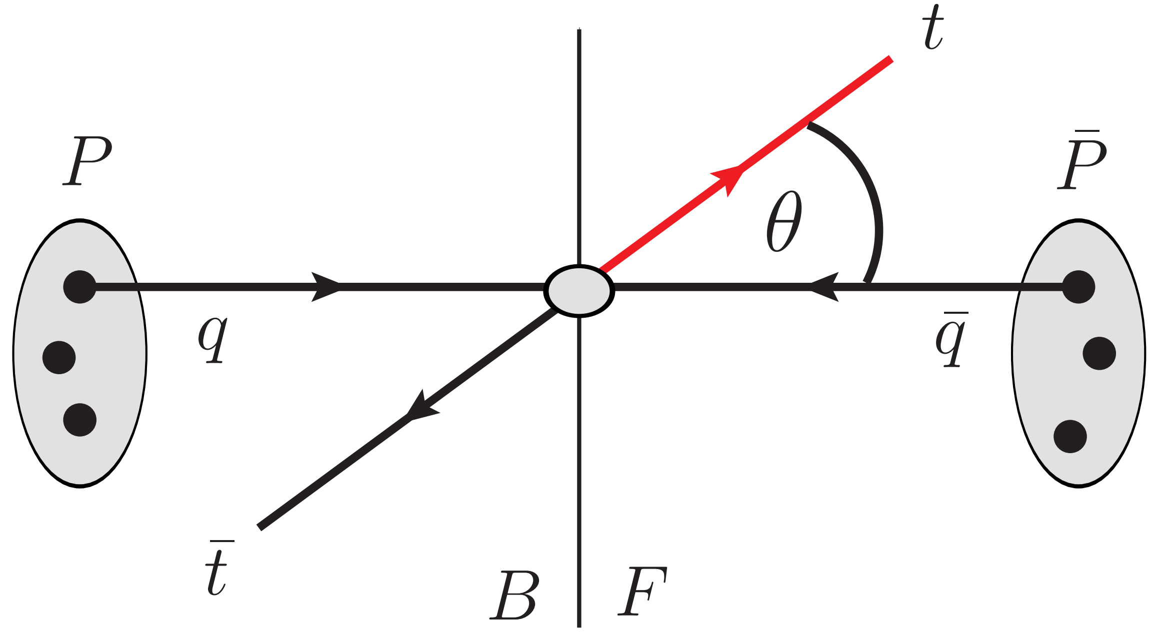
Outline

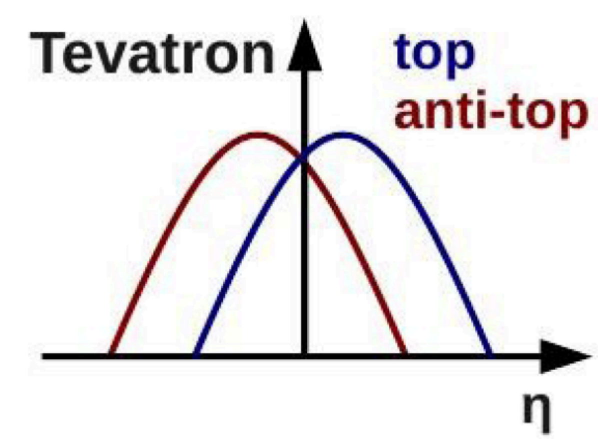
- Persistent hints of anomalous FBA in $t\bar{t}$ production at Tevatron
    - NP proposals (phenomenological approach)
- Impact of existing LHC measurements
- Possible future directions
    - Discriminating power of $t\bar{t}$ observables

FB & Charge asymmetries in $t\bar{t}$ production

- Charge (a)symmetric cross-section

$$\sigma_F \equiv \int_0^1 \frac{d\sigma}{d\cos\theta} d\cos\theta, \qquad \sigma_B \equiv \int_{-1}^0 \frac{d\sigma}{d\cos\theta} d\cos\theta.$$





$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} \qquad \Delta y = y_t - y_{\bar{t}}$$

FB & Charge asymmetries in $t\bar{t}$ production

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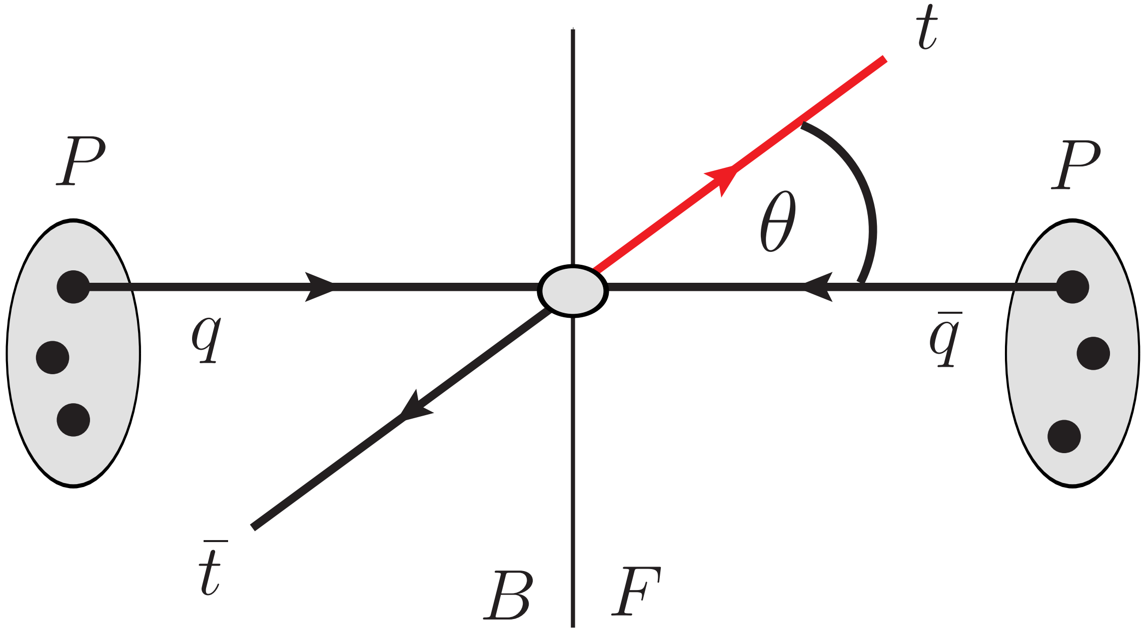
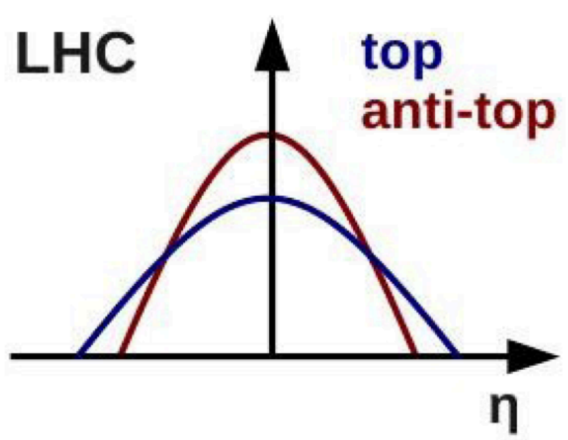




$$A_C = \text{sign}(Y)\frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{N(\Delta y^2 > 0) - N(\Delta y^2 < 0)}{N(\Delta y^2 > 0) + N(\Delta y^2 < 0)}$$

$$Y = y_t + y_{\bar{t}}$$
$$\Delta y^2 = y_t^2 - y_{\bar{t}}^2$$

FB & Charge asymmetries in $t\bar{t}$ production

- Non-zero $A_{FB,C}$ require $\hat{t}$-$\hat{u}$ odd contributions to σ

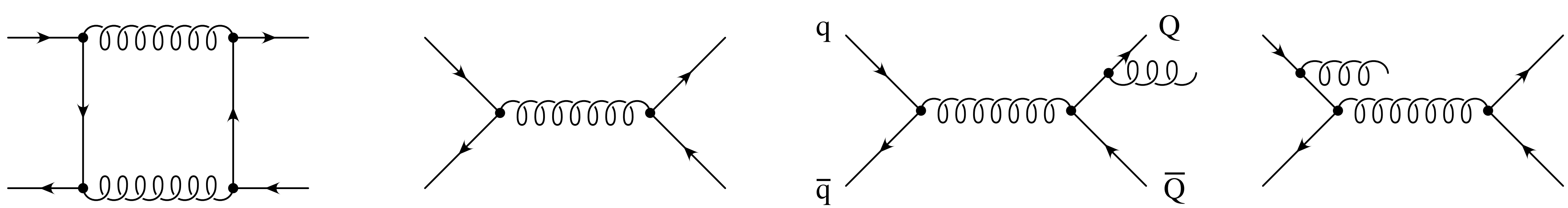
$$\hat{t}, \hat{u} = m_t^2 - \frac{\hat{s}}{2}[1 \mp \beta_t \cos\theta]$$

$$\beta_t = \sqrt{1 - \frac{4m_t^2}{\hat{s}}}$$

$$\hat{t} = (p_q - p_t)^2$$

$$\hat{s} = (p_t + p_{\bar{t}})^2$$

  - In QCD induced at order α_s^3

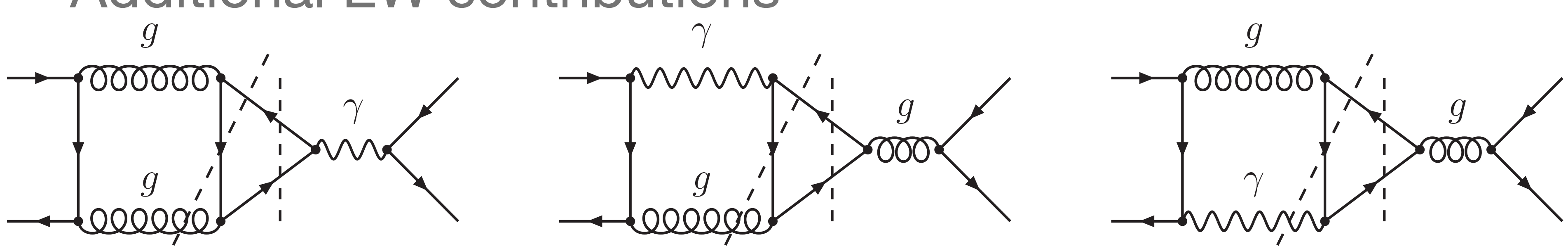


Kuhn & Rodrigo, hep-ph/9802268, hep-ph/9807420

Ahrens et al., 1106.6051

...

  - Additional EW contributions



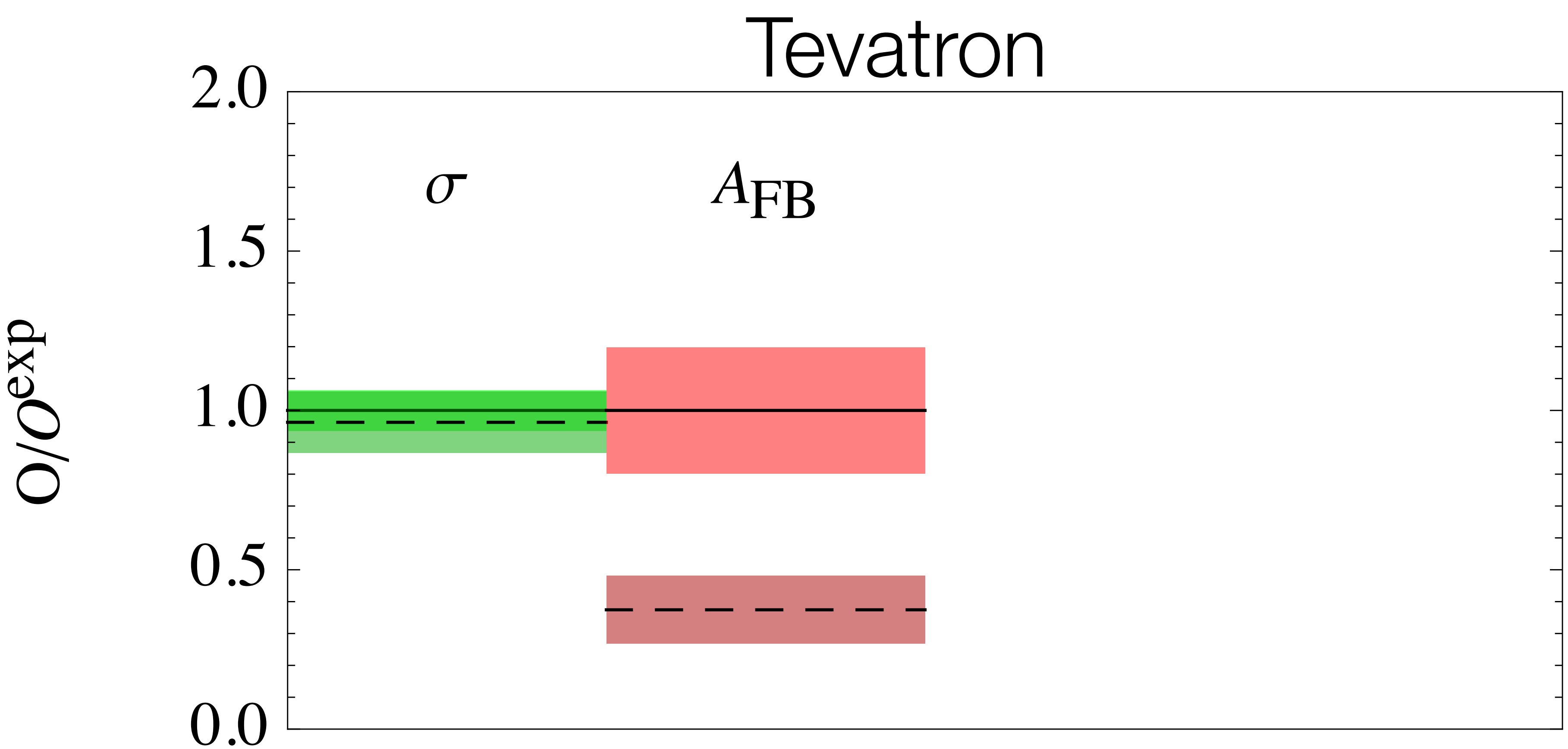
Hollik & Pagani, 1107.2606
Kuhn & Rodrigo, 1109.6830

- SM predictions for Tevatron: $A_{FB}^{SM} \sim 7 - 9\%$ ($q\bar{q}$ initial states dominate)

  LHC: $A_C^{SM} \sim 1\%$ (gg initial state dominates)

Measurements of $t\bar{t}$ production at Tevatron & LHC

- Precisely measured inclusive observables



$$\sigma = (7.50 \pm 0.48)\,\mathrm{pb} \qquad A_{FB} = 0.187 \pm 0.037^*$$

Kidonakis, 1009.4935
1105.3481

Beneke et al., 1109.1536
see also talks by
Mitov, Kidonakis, Yang

CDF, Public Notes
9913, 10398, 10807

D0, 1107.4995

*naive average of
CDF & DO
measurements

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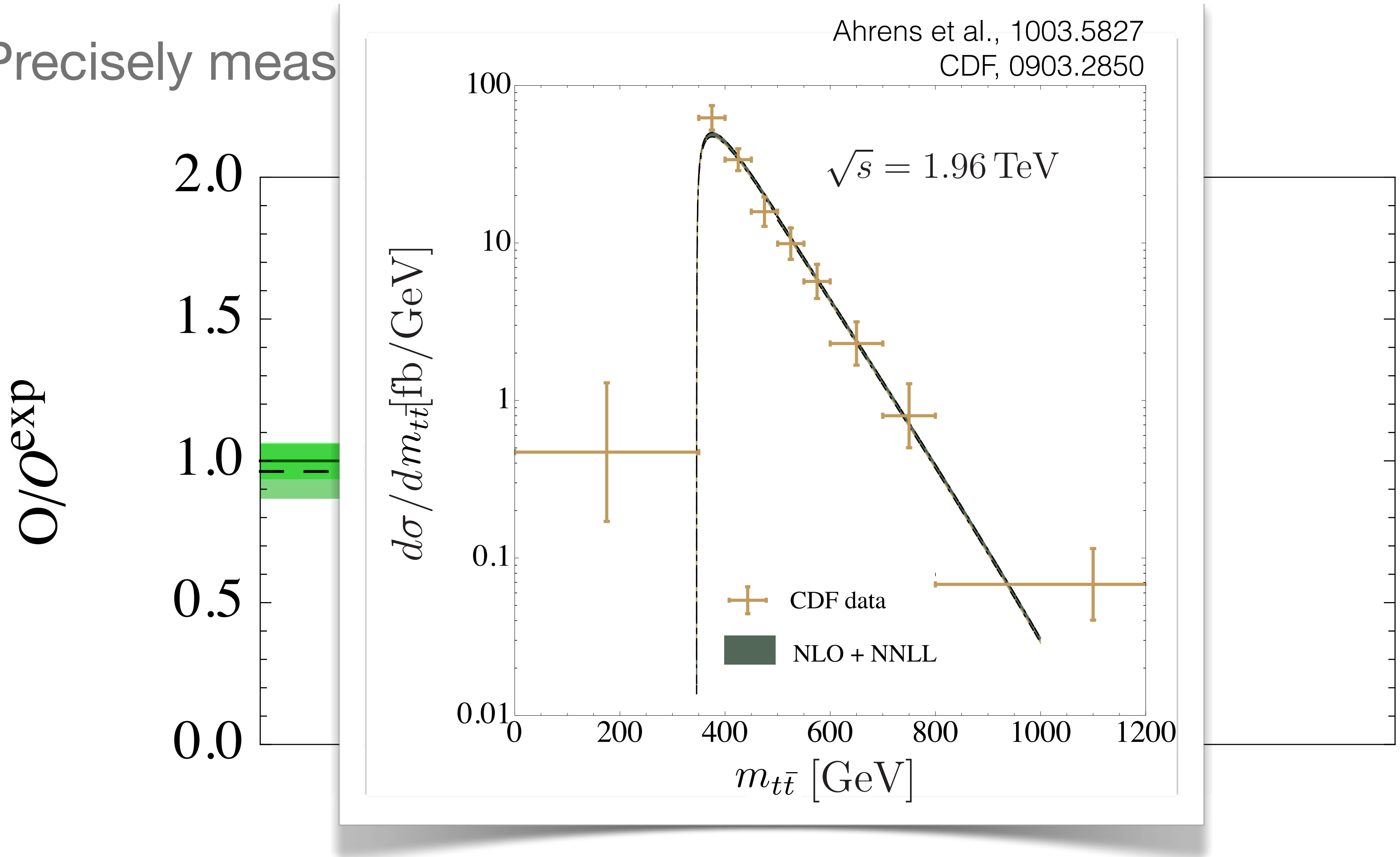

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- Sensitive m_{tt} exclusive observables

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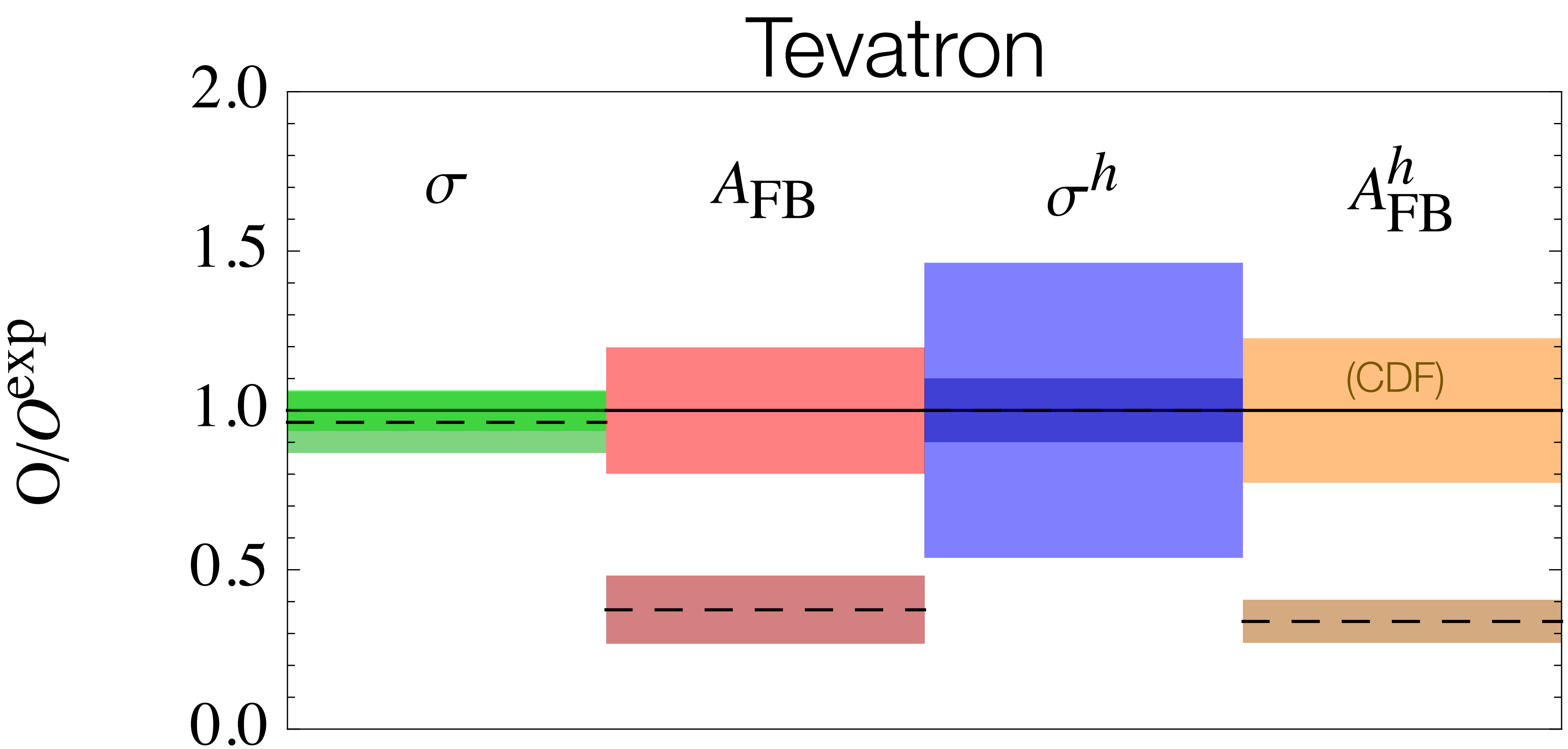

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1105.3481

Beneke et al., 1109.1536
see also talks by
Mitov, Kidonakis, Yang

Ahrens et al., 1003.5827
...

- Sensitive m_{tt} exclusive observables

$$\sigma^h = \sigma(700\text{GeV} < m_{t\bar{t}} < 800\text{GeV}) \quad A^h_{FB} = A_{FB}(m_{t\bar{t}} > 450\text{GeV})$$

CDF, Public Notes
9913, 10398, 10807

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CDF, 0903.2850
see talks by
Soustruznik, Vellidis

Measurements of $t\bar{t}$ production at Tevatron & LHC

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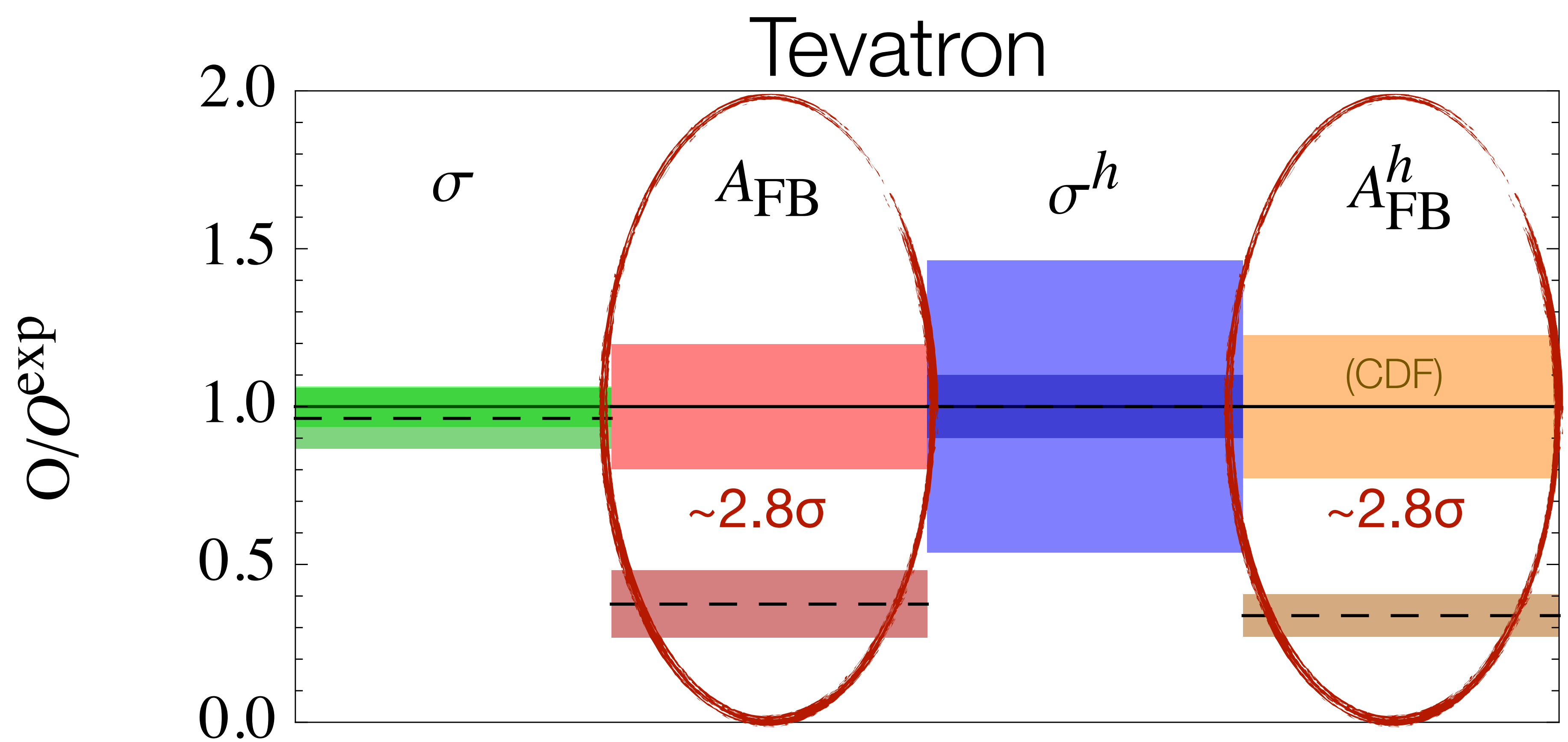

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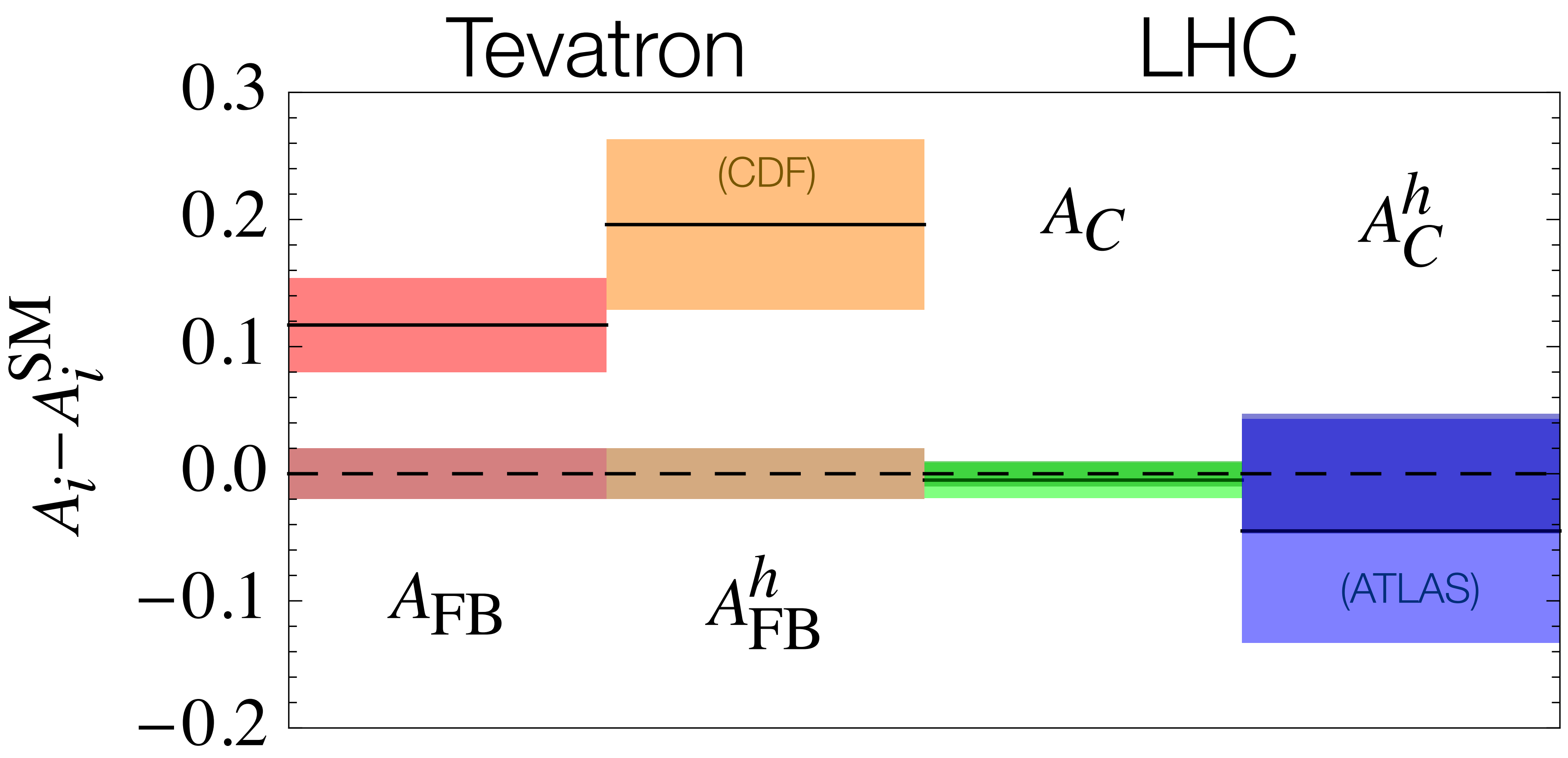
Measurements of $t\bar{t}$ production at Tevatron & LHC

- Confronting Tevatron A_{FB} & LHC A_C measurements



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Ahrens et al., 1003.5827
...

$$A_C = 0.001 \pm 0.014 \; ^*$$

$$A_C^h = -0.008 \pm 0.047 \quad \text{(ATLAS)}$$

ATLAS, 1203.4211
CMS, PAS-TOP-11-306
ATLAS-CONF-2011-106

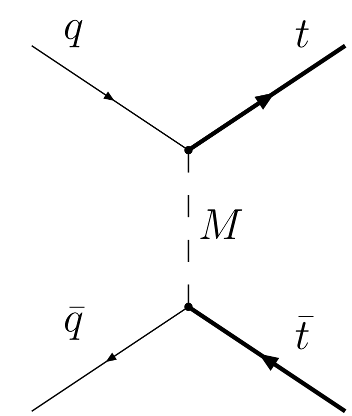
*naive average of
ATLAS & CMS
measurements

No deviations seen at the LHC!

New Physics Interpretation(s)

c.f. Kamenik, Shu, Zupan, 1107.5257

- ***t(u)-channel resonances***
  - Z', W', H', scalar color triplets, sextets,...
  - asymmetries driven by kinematics (Rutherford scattering)



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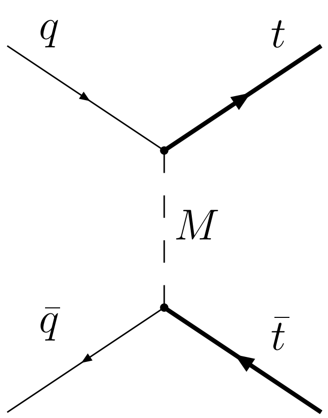
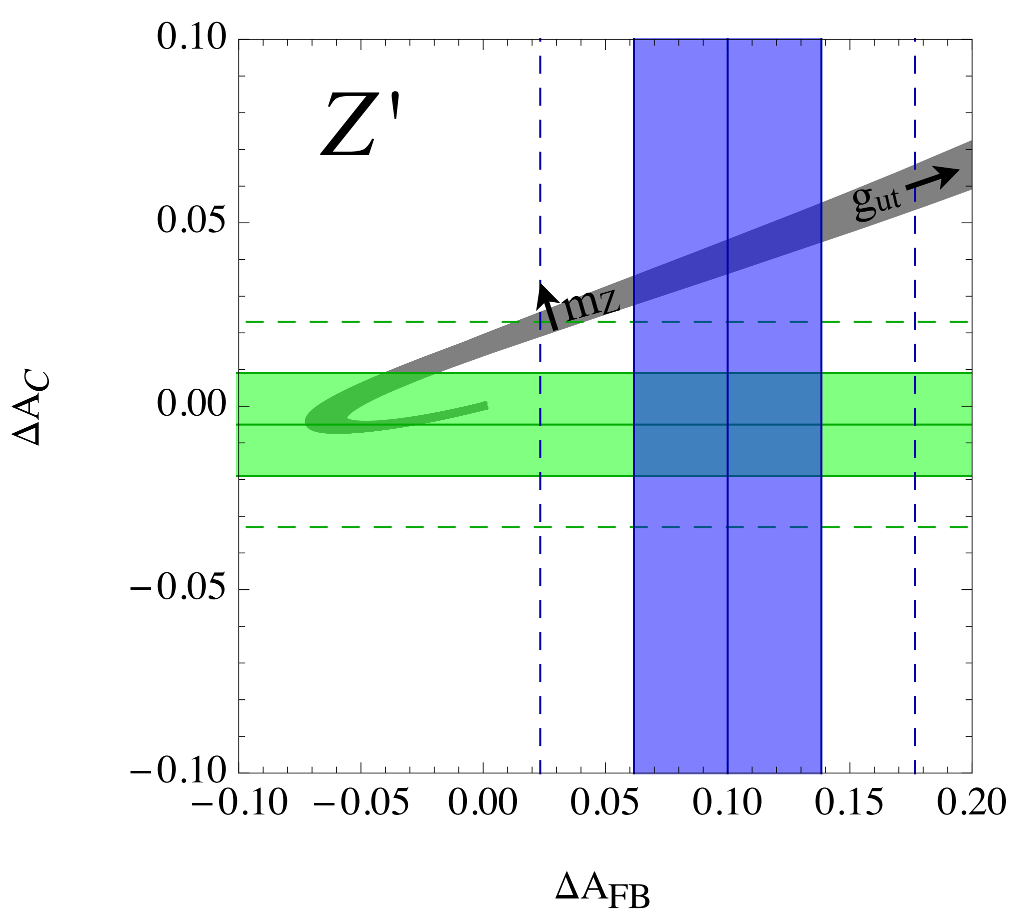
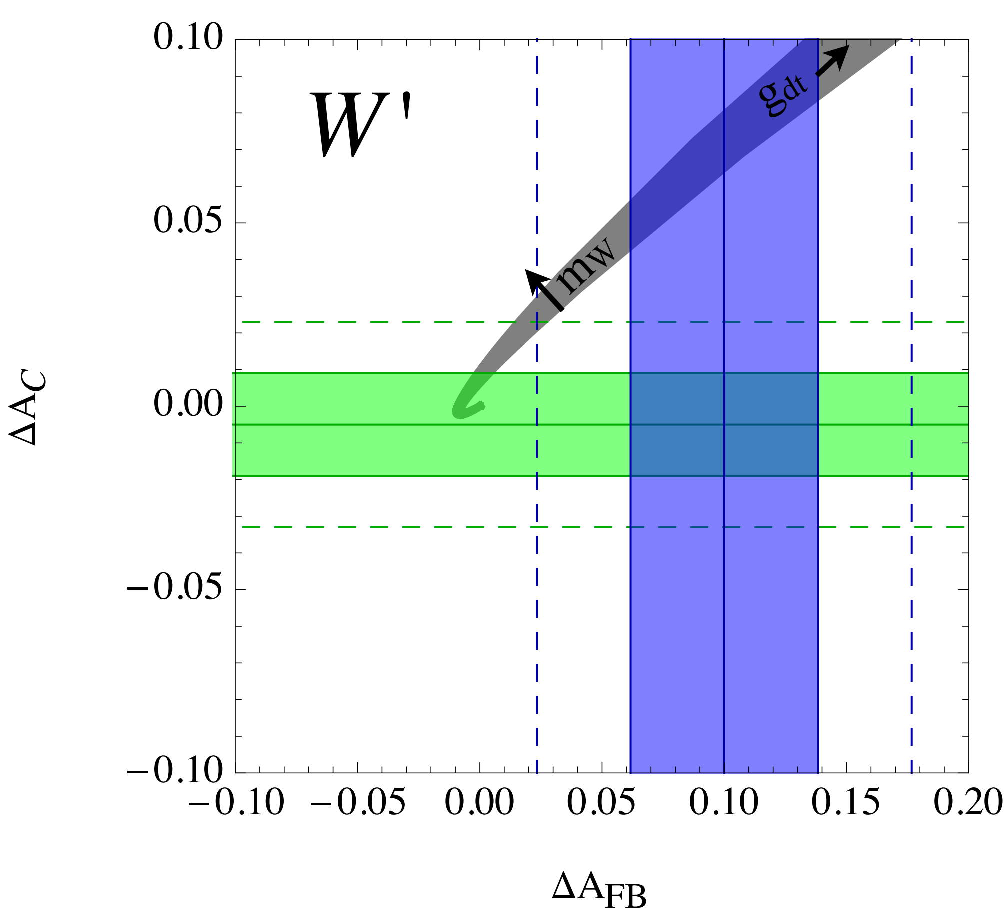
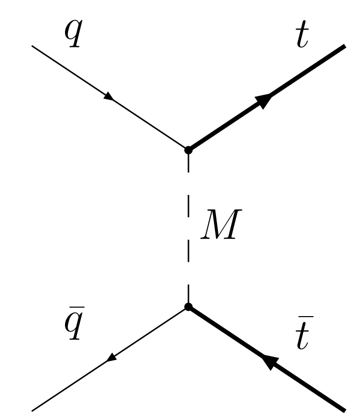






Fajfer, J.F.K., Melic, to appear.

New Physics Interpretation(s)



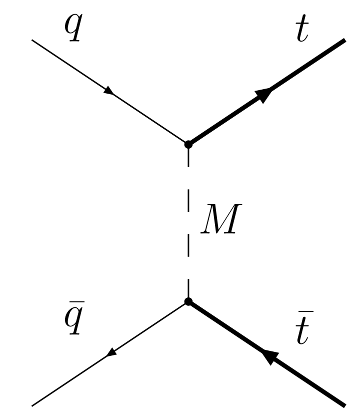
- ***t(u)-channel resonances***
  - Z', W', H', scalar color triplets, sextets,...
  - asymmetries driven by kinematics (Rutherford scattering)
  - Present impact of LHC: Z', W' incompatible with combined A_{FB} & A_C values
    - expect sizable σ excess in the forward region: **top quarks at LHCb?**
      Kagan, J.F.K., Perez & Stone, 1103.3747
    - alternatively extend rapidity coverage of semileptonic $t\bar{t}$ events at ATLAS & CMS - **y dependent charge asymmetries**
      Arguin et al., 1107.4090

Antunano et al., 0709.1652

Hewett et al., 1103.4618

New Physics Interpretation(s)

- ***t(u)-channel resonances***

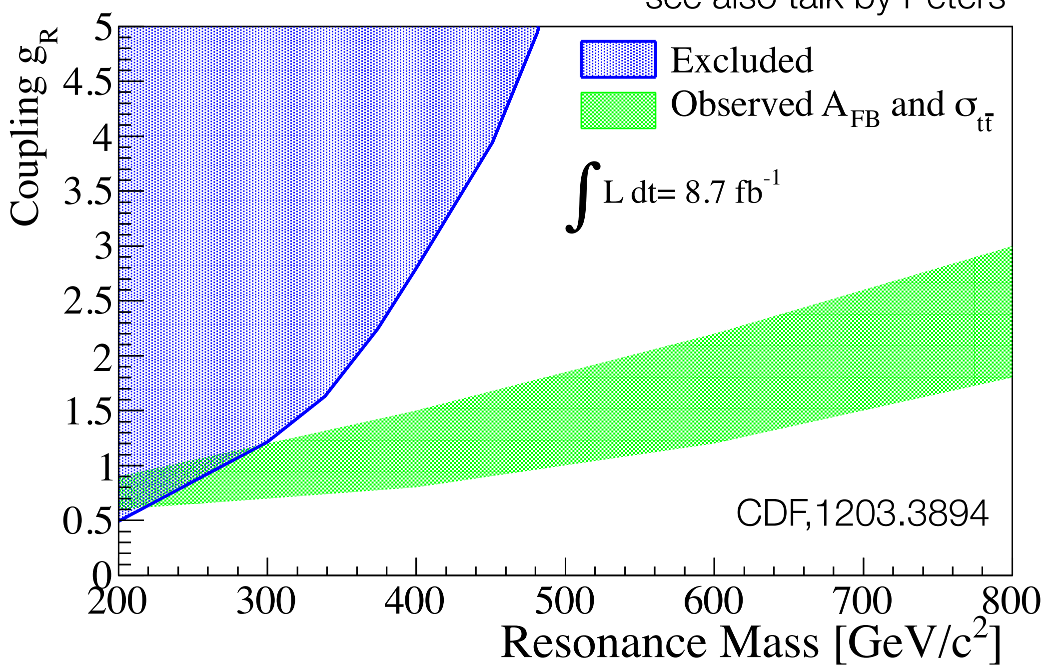


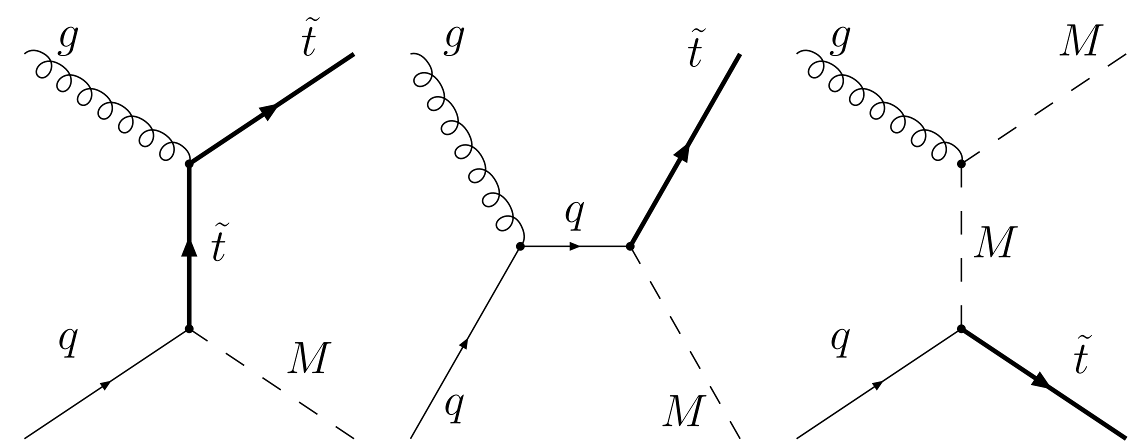
  - Z’, W’, H’, scalar color triplets, sextets,...
  - asymmetries driven by kinematics (Rutherford scattering)
  - Present impact of LHC: Z’, W’ incompatible with combined A_{FB} & A_C values
  - predict flavor violating **(t-j) resonances** in t-associated production

Gresham et al., 1102.0018

...

see also talk by Peters





Singlet models.

New Physics Interpretation(s)

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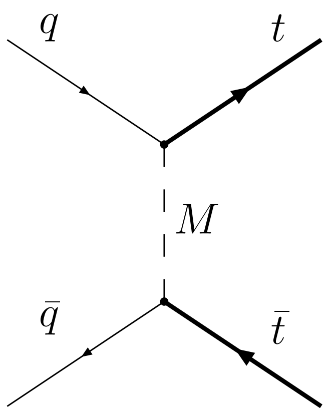

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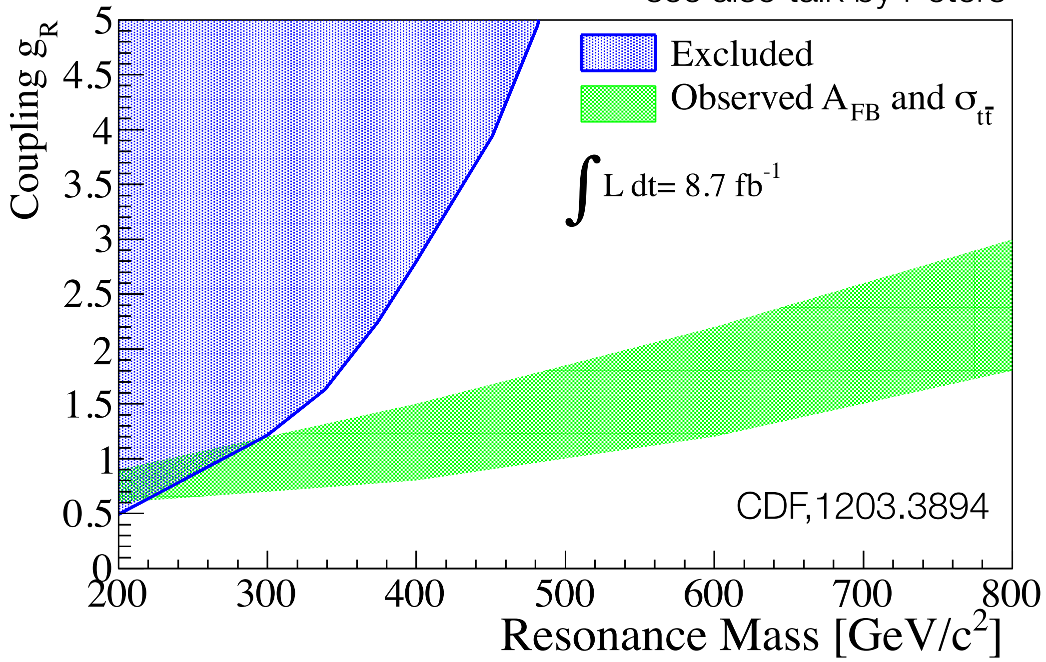

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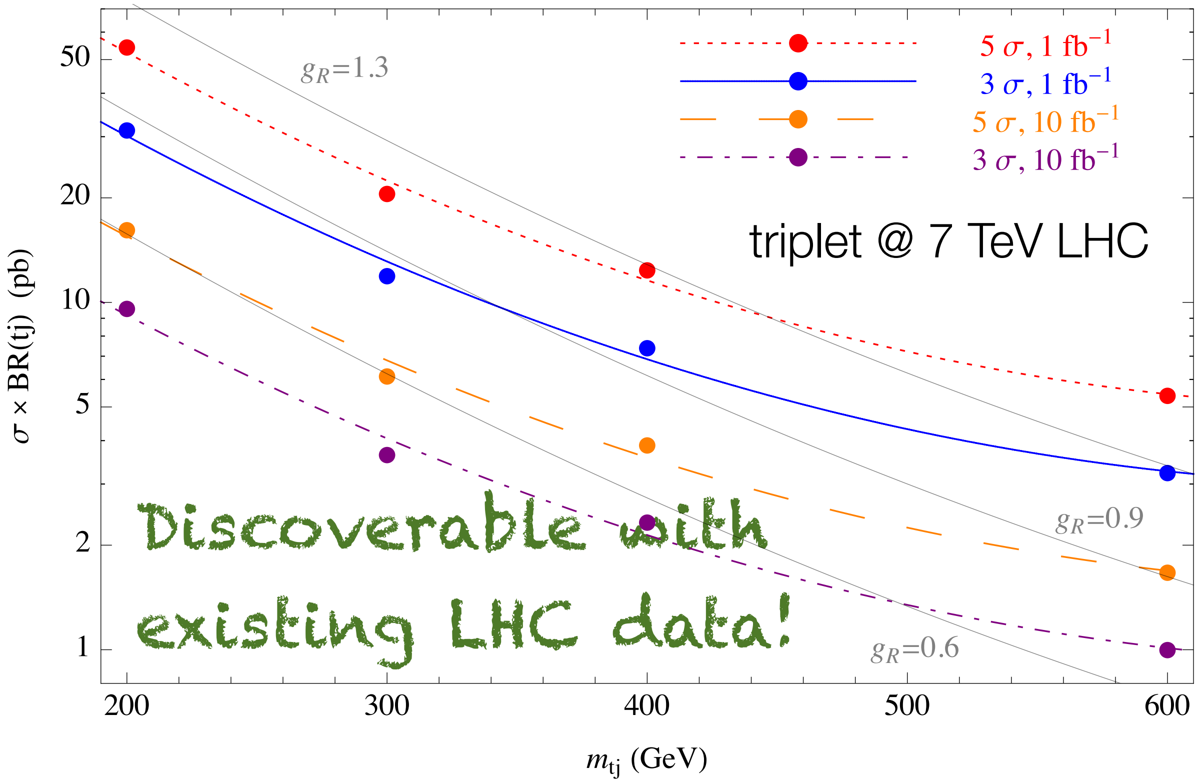

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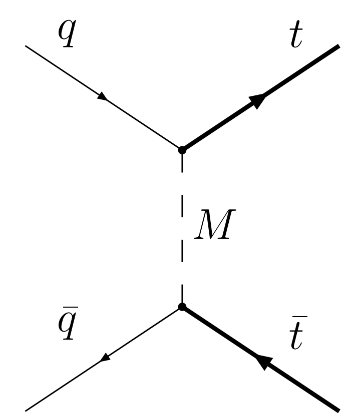
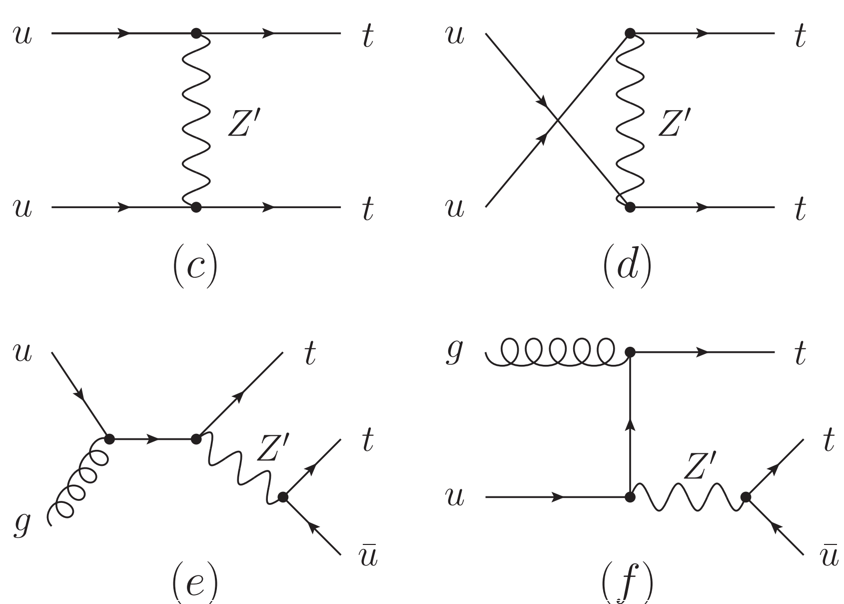


  - Z', W', H', scalar color triplets, sextets,...
  - asymmetries driven by kinematics (Rutherford scattering)
  - Present impact of LHC: Z', W' incompatible with combined A_{FB} & A_C values
  - predict flavor violating **(t-j) resonances** in t-associated production
  - same-sign top pair production can be a problem - model-dependent

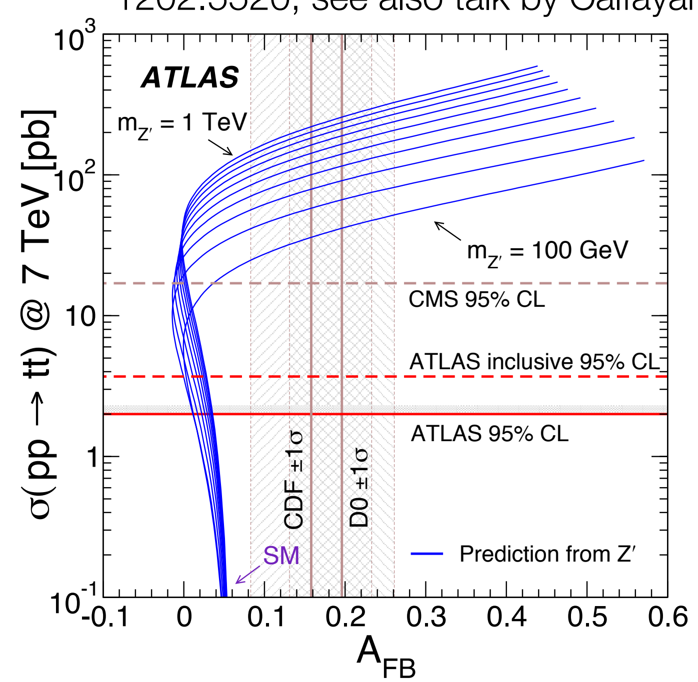
Aguilar-Saavedra & Perez-Victoria, 1104.1385

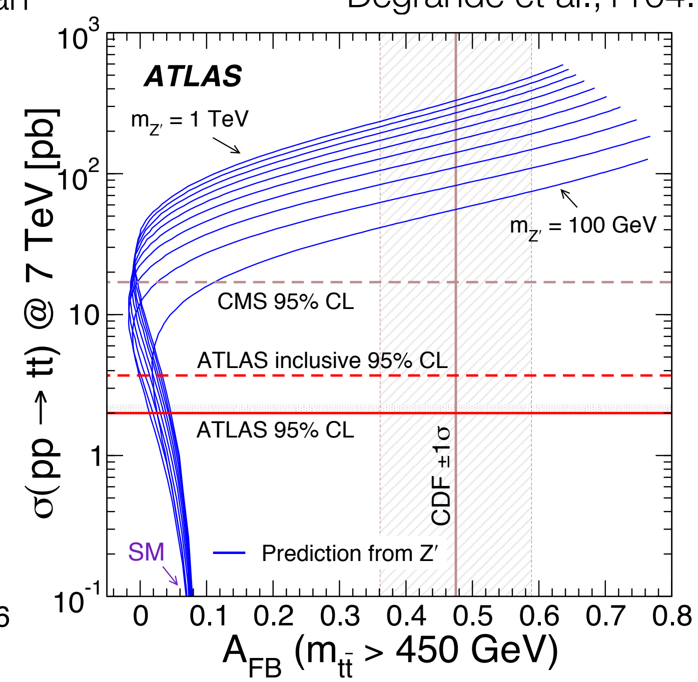
Degrande et al.,1104.1798

Z' of Berger et al., 1101.5625



1202.5520, see also talk by Calfayan

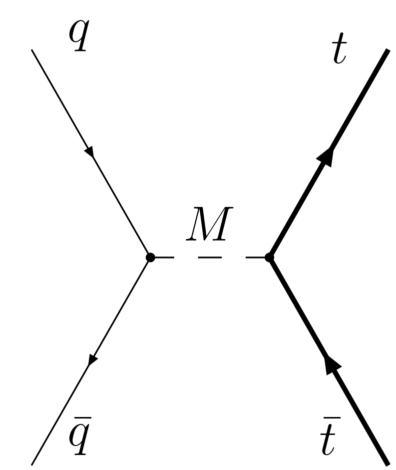




New Physics Interpretation(s)

c.f. Kamenik, Shu, Zupan, 1107.5257

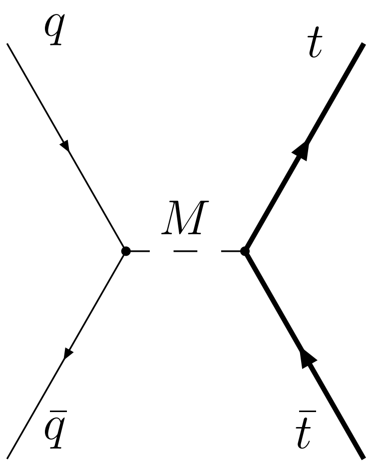
- ***s-channel resonances (KK or “Axigluon”, also EFT*)***
    - asymmetries driven by spin interference effects



*c.f. Delaunay et al., 1103.2297

New Physics Interpretation(s)

- ***s-channel resonances (KK or "Axigluon", also EFT*)***
  - asymmetries driven by spin interference effects
    - top spins at threshold probe initial state chiralities
    - use **leptonic asymmetries** as probes

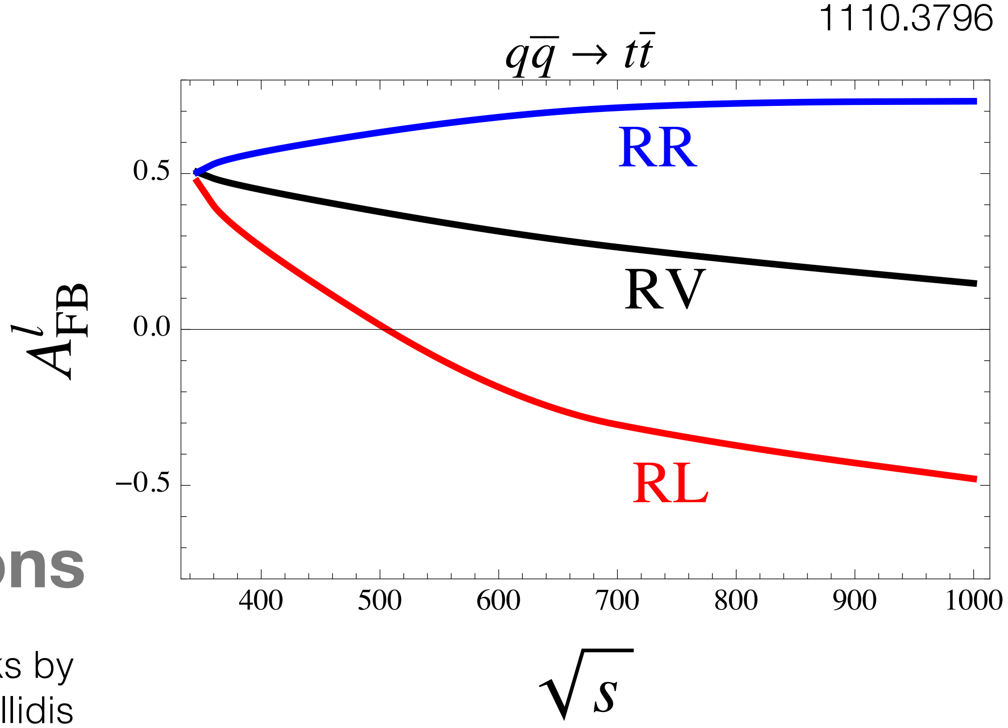


$$A^{\ell}_{\rm FB} = \frac{N_l(q_l \cos\theta_l > 0) - N_l(q_l \cos\theta_l < 0)}{N_l(q_l \cos\theta_l > 0) + N_l(q_l \cos\theta_l < 0)}$$

First exp. result by D0, 1107.4995

see talk by Soustruznik

Falkowski, Perez & Schmaltz 1110.3796



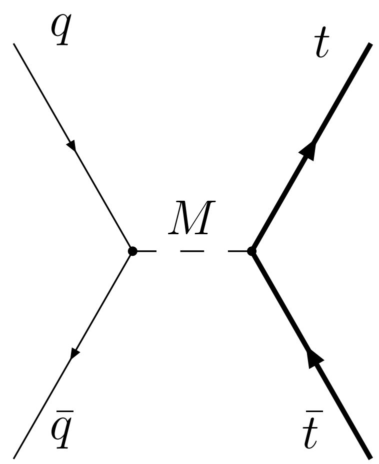
- at large m_{tt} interesting **spin correlations**

G. Mahlon and S. J. Parke hep-ph/9512264
Bernreuther et al., hep-ph/0403035
Hewett et al., 1103.4618
Krohn et al., 1105.3743
Bai et al., 1106.5071
Berger et al., 1201.1790

see talks by Head, Vellidis Hirose

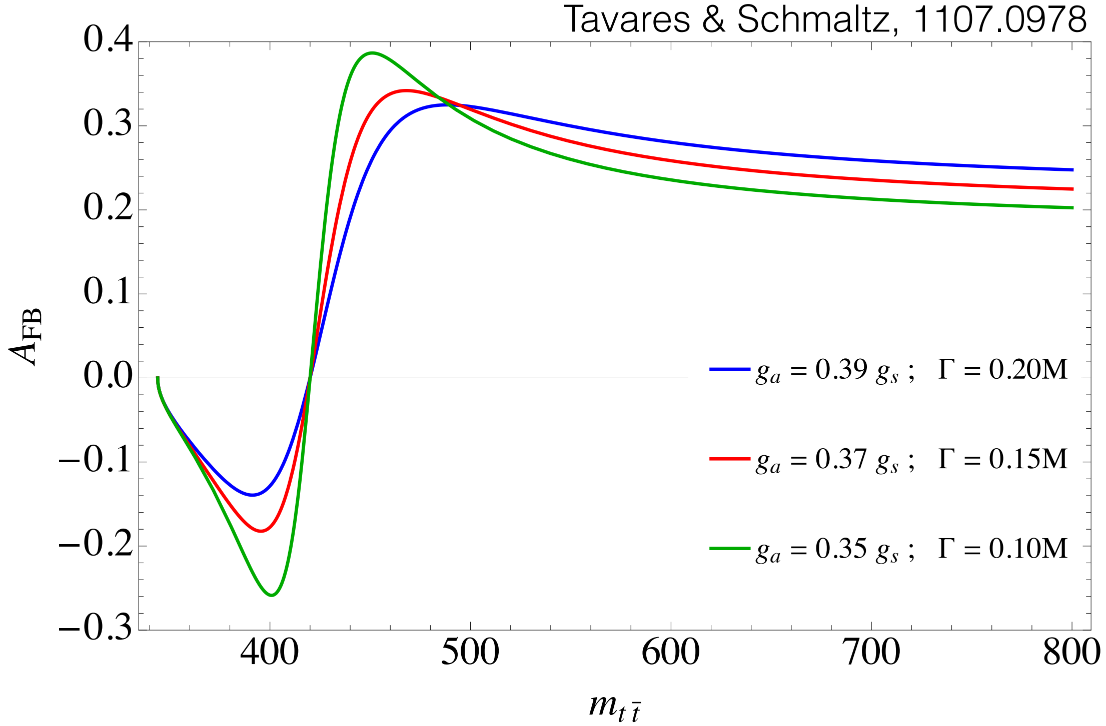
New Physics Interpretation(s)

- ***s-channel resonances (KK or "Axigluon", also EFT*)***
  - asymmetries driven by spin interference effects
  - need color octet axial vector contributions
    - m_{tt} differential $A_{FB,C}$ change sign at resonance mass
      - Tevatron data suggest



$$M \lesssim 400 \text{ GeV}$$
or
$$M \gtrsim 1 \text{ TeV}$$

Tavares & Schmaltz, 1107.0978



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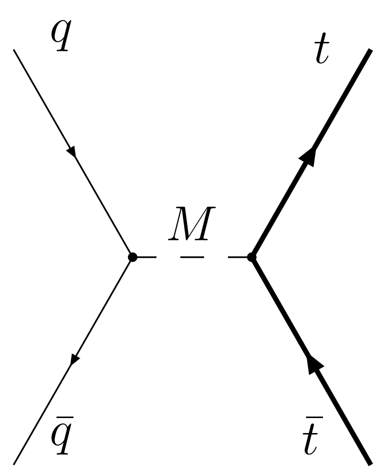
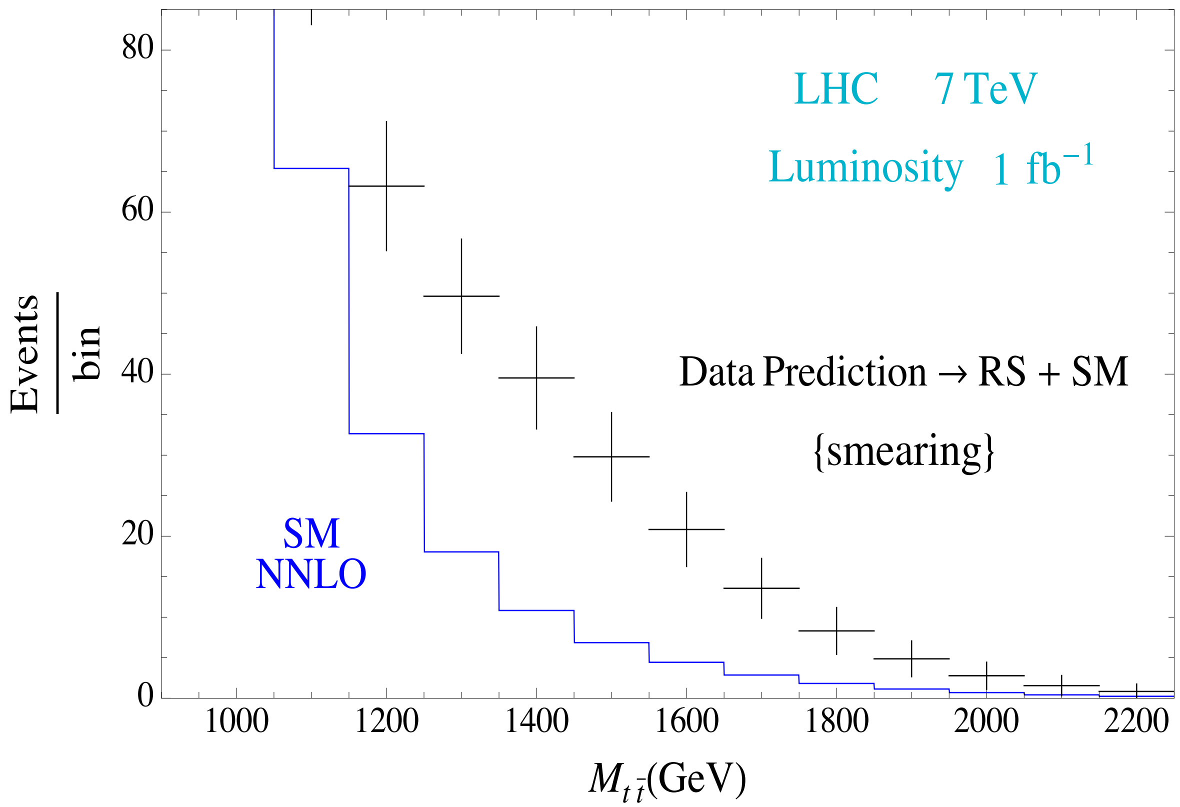
  - need color octet axial vector contributions
    - m_{tt} differential $A_{FB,C}$ change sign at resonance mass
  - predict resonance in m_{tt}
    - may be very broad



Djouadi et al., 1105.3158



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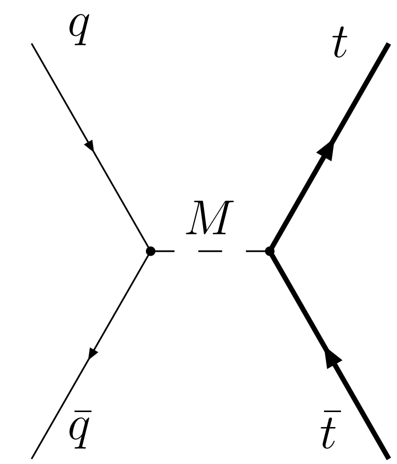
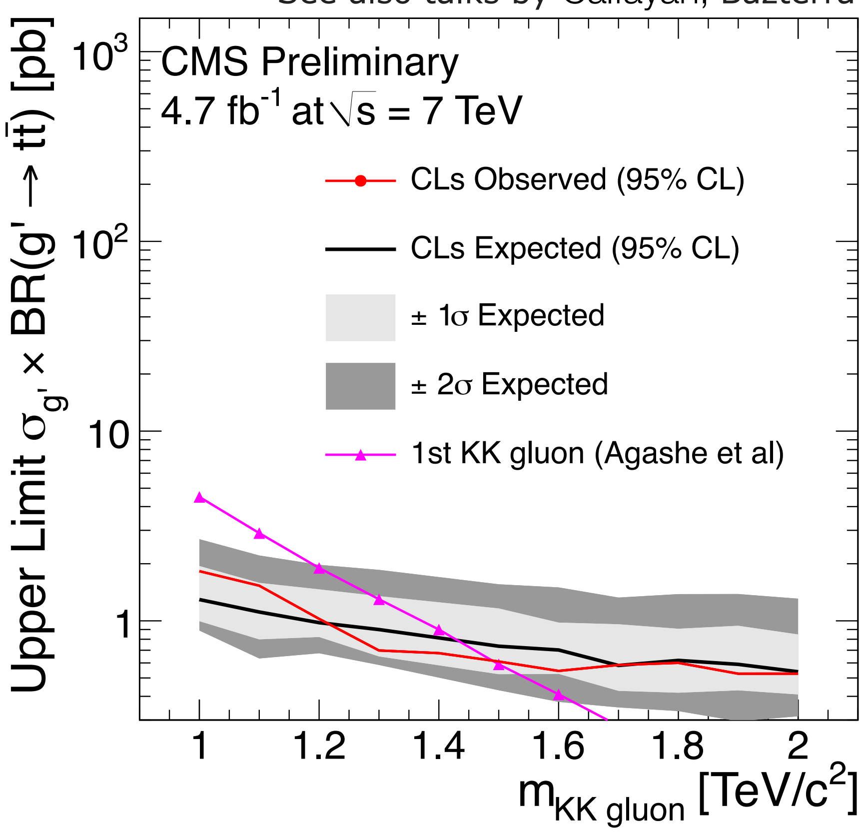
    - may be very broad [Br($t\bar{t}$)<<1]



care needed when interpreting LHC bounds

ATLAS CONF-2012-029
CMS PAS TOP-11-009
See also talks by Calfayan, Bazterra



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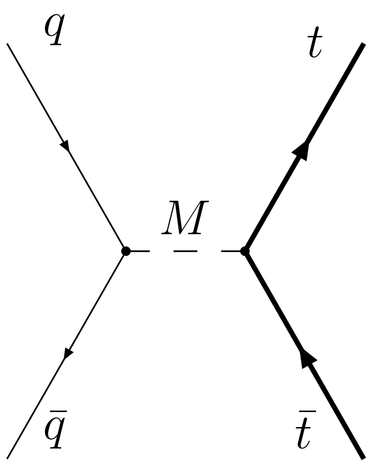
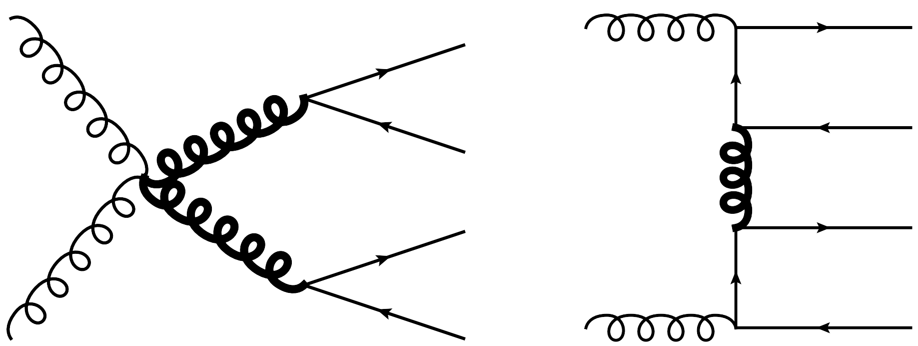
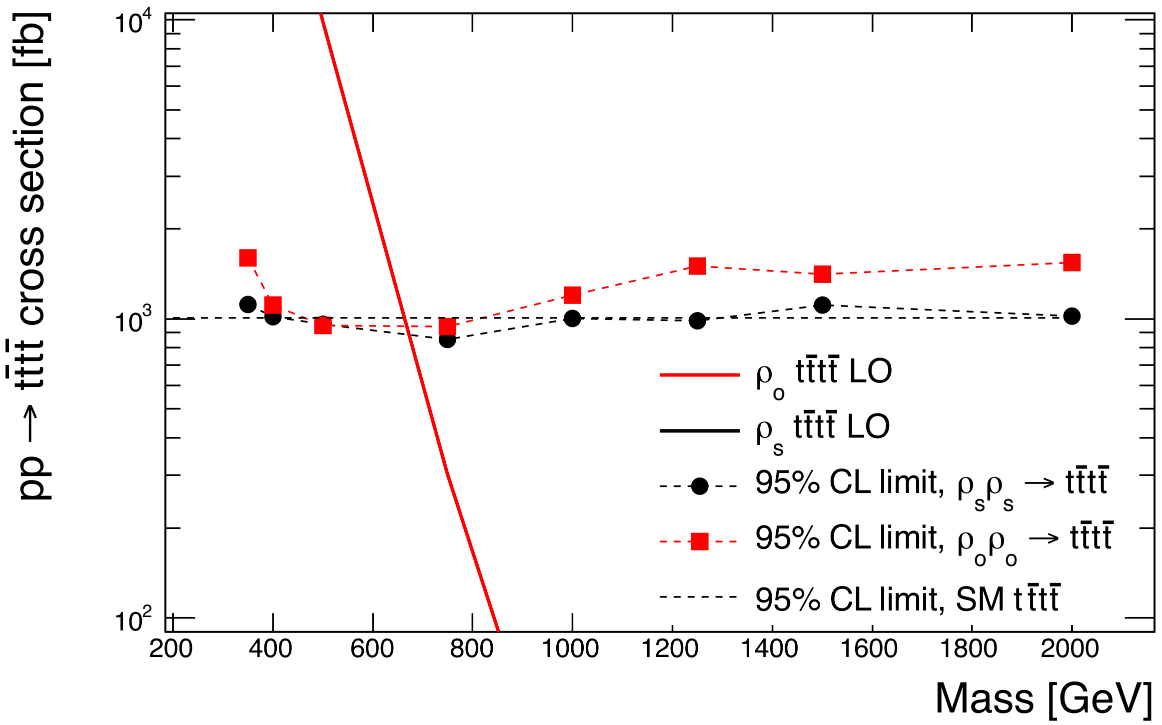
    - may be very broad
  - also (resonant) 4-top production





Zhou et al., 1203.5862
using ATLAS, 1202.5520



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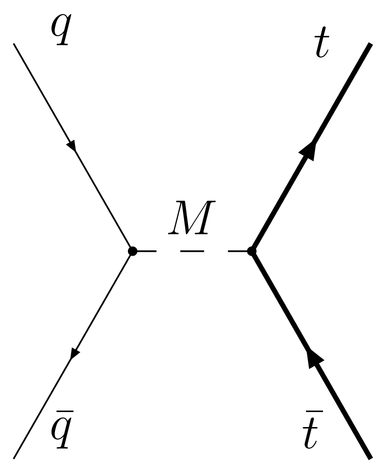
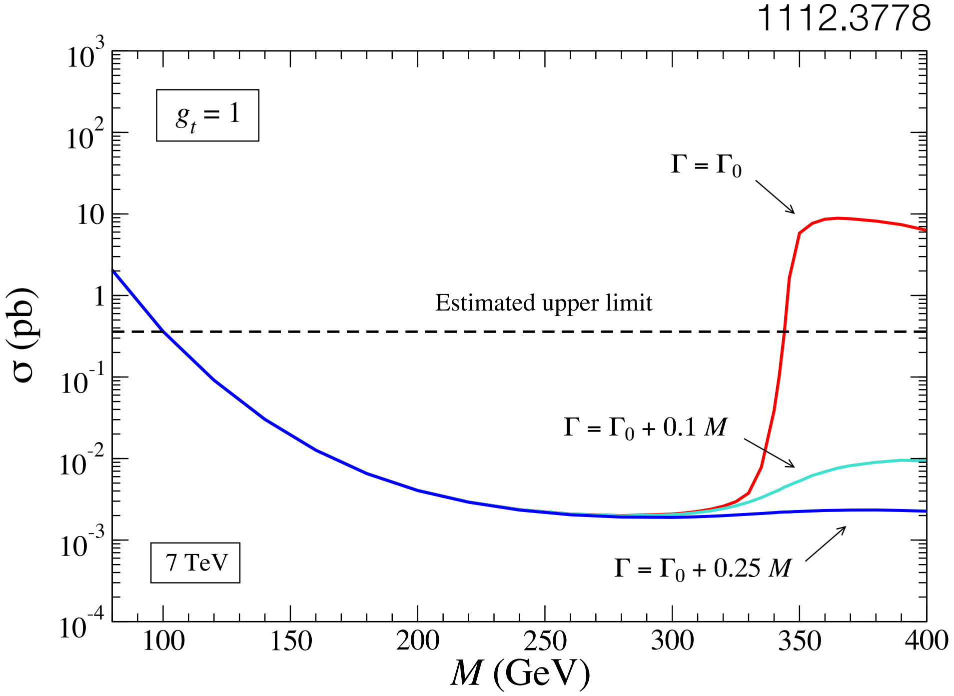
  - also (resonant) 4-top production
    - large widths can again upset the limits



Aguilar-Saavedra & Santiago
1112.3778



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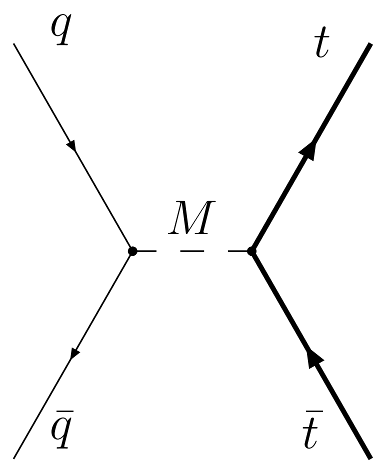

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  - predict resonance in m_{tt}
    - may be very broad
  - also (resonant) 4-top production
    - large widths can again upset the limits
  - however, complementary dijet resonance searches

Chivukula et al., 1007.0260.
Delaunay et al., 1101.2902
Bai et al., 1101.5203

Concrete models already very constrained

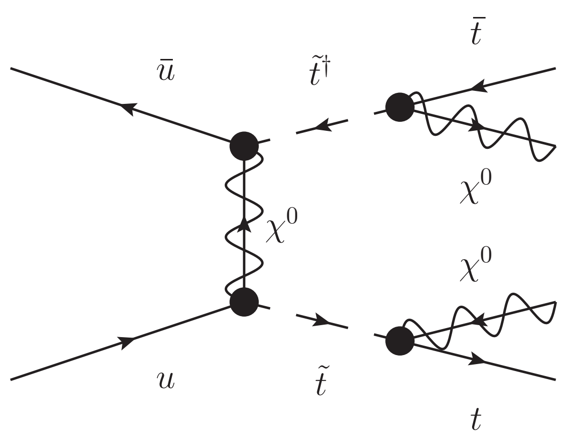
CMS, PAS EXO-11-016
1107.4771
ATLAS, 1108.6311

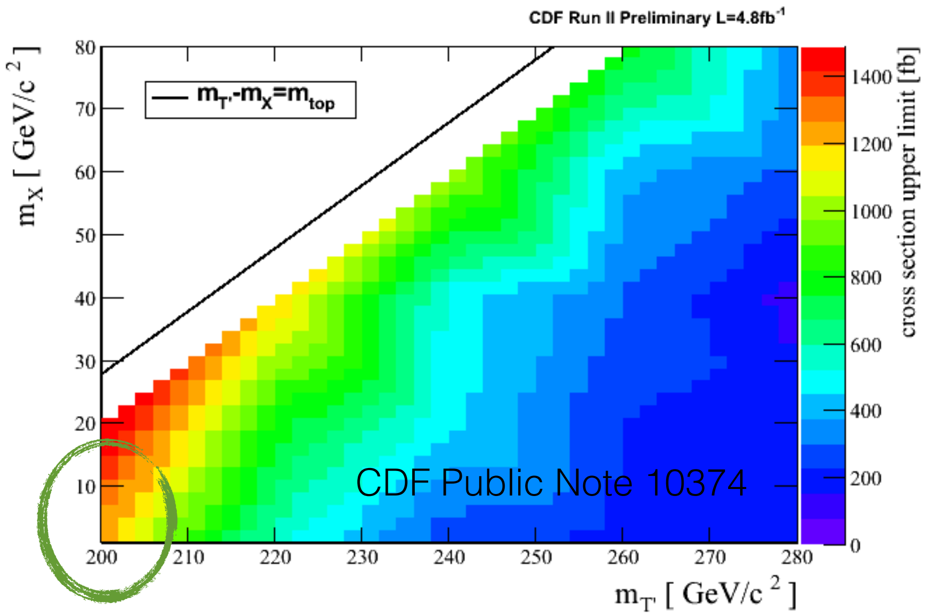
New Physics Interpretation(s)

- ***Incoherent $t\bar{t}$ production*** Isidori & J.F.K. 1103.0016
    - Production of “top partners” decaying to top + invisible particles
    - Need to pass $t\bar{t}$ selection criteria and escape searches for $t\bar{t}+E_{miss}$
    - QCD production of scalars mostly p-wave, vanishes at threshold!
        - ‘4th gen’ exclusions do not apply!
        - In low mass region sizable σ still allowed
            - $m_{\tilde{t}}$~190GeV, m_χ~O(GeV)

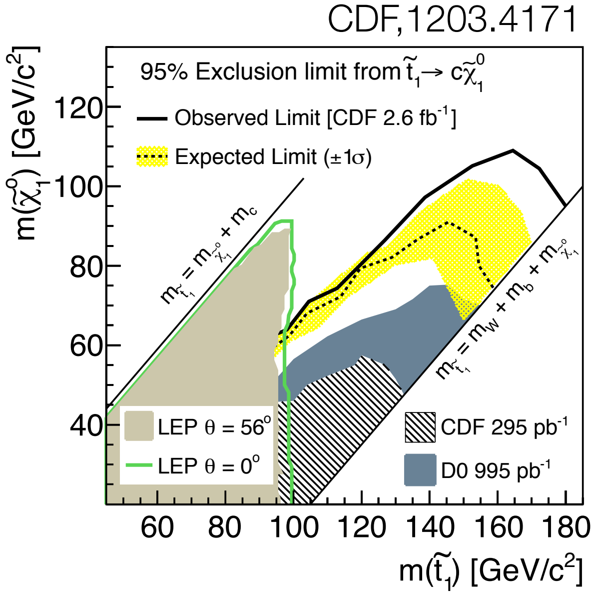
ATLAS, TOPQ-2011-09

Beenakker et al., 1006.4771





CDF,1203.4171



Conclusions

- ***The most significant hints of BSM physics at the Tevatron in top sector***
  - Large measured A_{FB} could still be due to O(TeV) (s-channel) resonances
    - at LHC expect excess in di-jet & $t\bar{t}$ spectra - already constrain such NP
  - Interesting possibilities of sub TeV contributions in u- or t-channel
    - predicted LHC signatures in $t\bar{t}$+jets - *opportunity for ATLAS & CMS*

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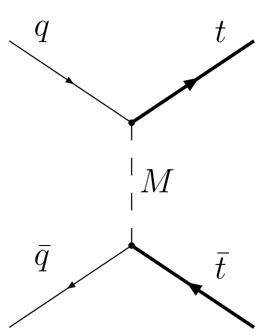
    - Enhanced σ_t in forward region - *opportunity for LHCb*
  - Also top polarization, spin correlations affected by NP addressing A_{FB}
    - related leptonic angular asymmetries
  - For incoherent A_{FB} contributions, expect $t\bar{t}+E_{miss}$, $jj+E_{miss}$

Looking forward to more exciting results from the LHC

Backup

New Physics Interpretation(s)



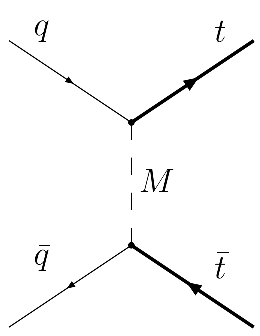
- ***t(u)-channel resonances***
  - Z', W', H', scalar color triplets, sextets,...
  - Need large FC (u-t, d-t) couplings
    - potentially severe constraints from ΔF=2 and <u>dijet searches</u>
      - first significant impact of LHC data with >1fb^{-1}
        - Tevatron still more sensitive if NP light!
      - important constraints from dijet angular distributions

ATLAS, 1108.6311
CMS, 1107.4771

Grinstein et al., 1102.3374
1108.4027

New Physics Interpretation(s)

- ***t(u)-channel resonances***
  - Z', W', H', scalar color triplets, sextets,...
  - Need large FC (u-t, d-t) couplings
    - potentially severe constraints from ΔF=2 and dijet searches
    - requires non-trivial flavor structure of the underlying theory
      - gauge symmetries $$-\frac{\lambda_{ij}^{\psi}}{2}\epsilon^{abc}\phi_a\psi_{Rb}^{iT}C\psi_{Rc}^{j}$$
      - flavor symmetries $$(\bar{U}_R T^A\gamma^\mu U_R)V_\mu^A = \left(V_\mu^4 - iV_\mu^5\right)\left(\bar{t}_R\gamma^\mu u_R\right) + \cdots$$



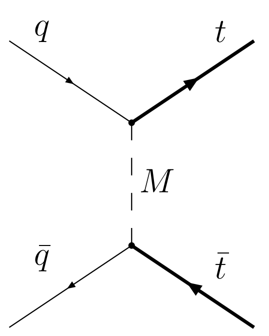
I. Dorsner, S. Fajfer, J.F.K., N. Kosnik, 0912.0972, 1007.2604
Giudice et al., 1105.3161

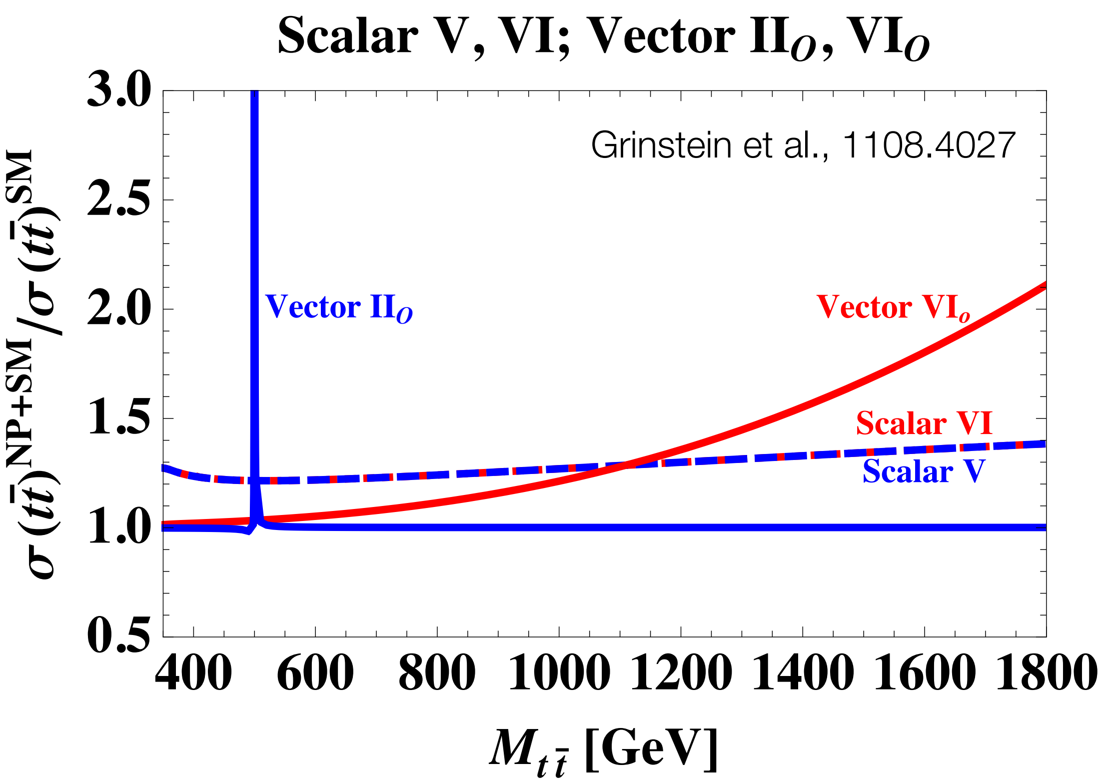
Grinstein et al., 1102.3374
Ligeti et al., 1103.2757
Jung et al., 1103.4835

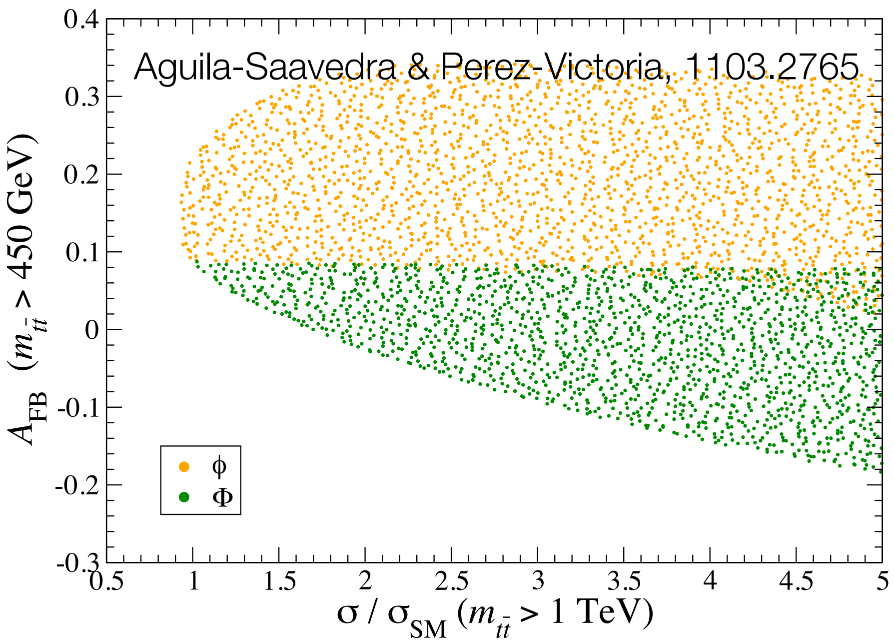
see also
J. Shelton & K. M. Zurek, 1101.5392

New Physics Interpretation(s)

- ***t(u)-channel resonances***
  - Z', W', H', scalar color triplets, sextets,...
  - Need large FC (u-t, d-t) couplings
  - Generically predict slow rise in m_{tt} spectrum







LHC~~b~~ t

Kagan, J.F.K., Perez & Stone, 1103.3747

- Top quarks at LHCb identified via **single muon** and **b-tagged high-p_T jet**
- Backgrounds for $t\bar{t}$:
  - Real muons, jets: W+$b\bar{b}$, W+jets
  - Fake muons, jets: $b\bar{b}$, jj
- Prospects for top charge asymmetry measurement
  - top rest-frame cannot be reconstructed
  - use μ, b pseudorapidity distribution instead