Leptonic forward-backward asymmetry of top quark-antiquark pairs in the dilepton channel at DØ

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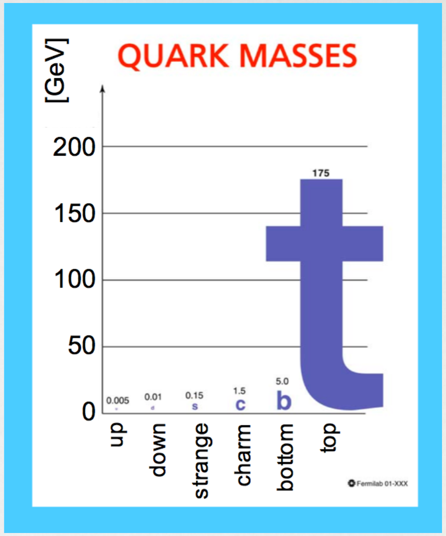
energie atomique • energies alternatives

The top quark

- ✗ Heaviest known elementary particle ($M_{top} \sim M_{gold\ atom}$)

$$\mathcal{L}_{Yukawa} = -\lambda_{top}\bar{\psi}_{l,top}\phi\psi_{r,top}$$

$$\lambda_{top} \approx 1$$



- ✱ top life time ~ 10^{-25}s << hadronization time
- ✱ M_{top}=173.20 ± 0.87 GeV
  Tevatron comb arXiv:1305.3929

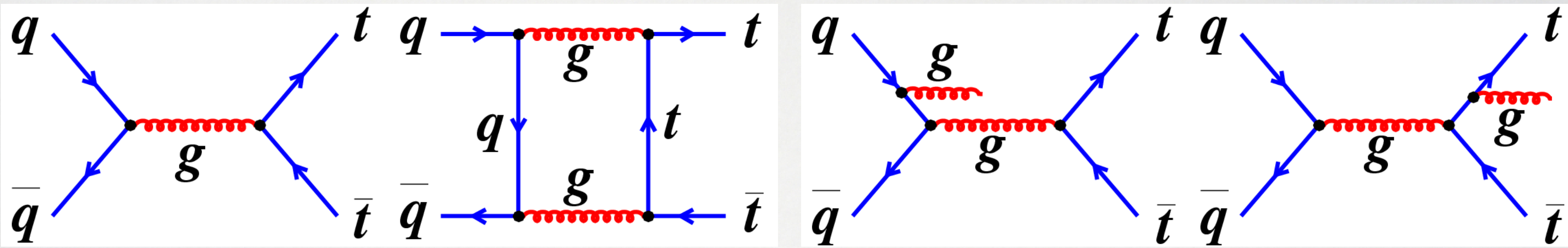
- ✗ Strong coupling to Higgs boson : special role ?
- ✗ Decays before hadronizing : study of a bare quark.

⇒ Ideal sector to search for new physics !
→ study the top quark properties in details.

Let's focus on the charge asymmetry

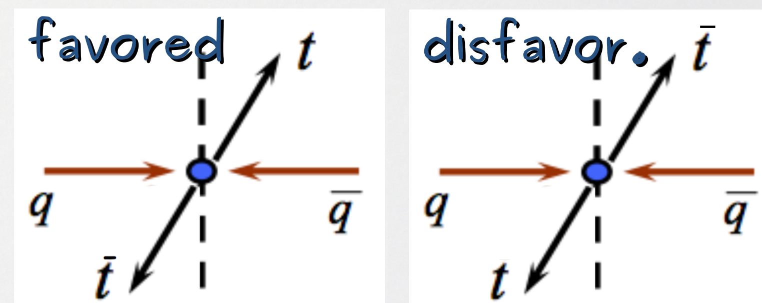
Charge asymmetry

At NLO, QCD predicts a $t\bar{t}$ production asymmetry via $q\bar{q}$ annihilation. Due to the interferences :

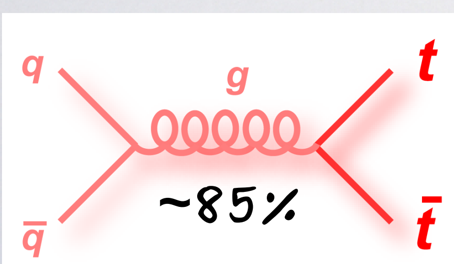


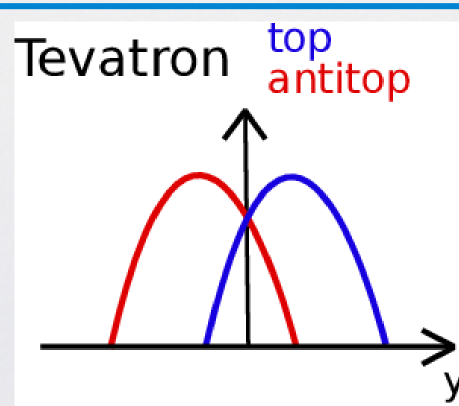
positive asymmetry > negative asymmetry

Kühn, Rodrigo Phys. Rev. Lett. 81, 49-52 (1998)



Non SM processes can modify the asymmetry (axigluon, Z' ...)



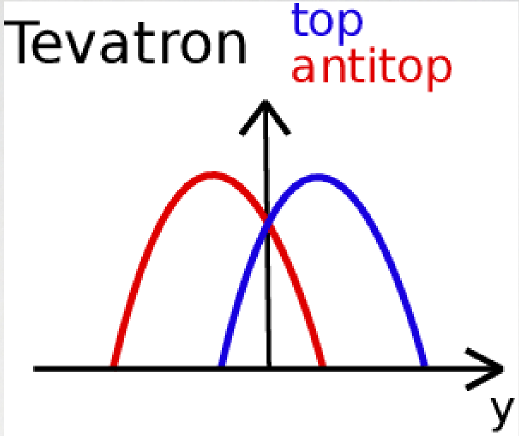


Tevatron:
Forward–Backward
asymmetry

Leptonic observables

✱ lepton-based asymmetry :

Looking at the leptons from the top quark decays



- ✗ no need to reconstruct the $t\bar{t}$ system & leptons are well measured
- ✗ influence from top polarization (if any)
- ✗ dilute asymmetry

Lepton's flight direction is correlated to the top's flight direction

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

$$\Delta\eta = \eta_{\ell+} - \eta_{\ell-}$$

$$A^{\ell}_{FB} = \frac{N(q\times\eta > 0) - N(q\times\eta < 0)}{N(q\times\eta > 0) + N(q\times\eta < 0)}$$

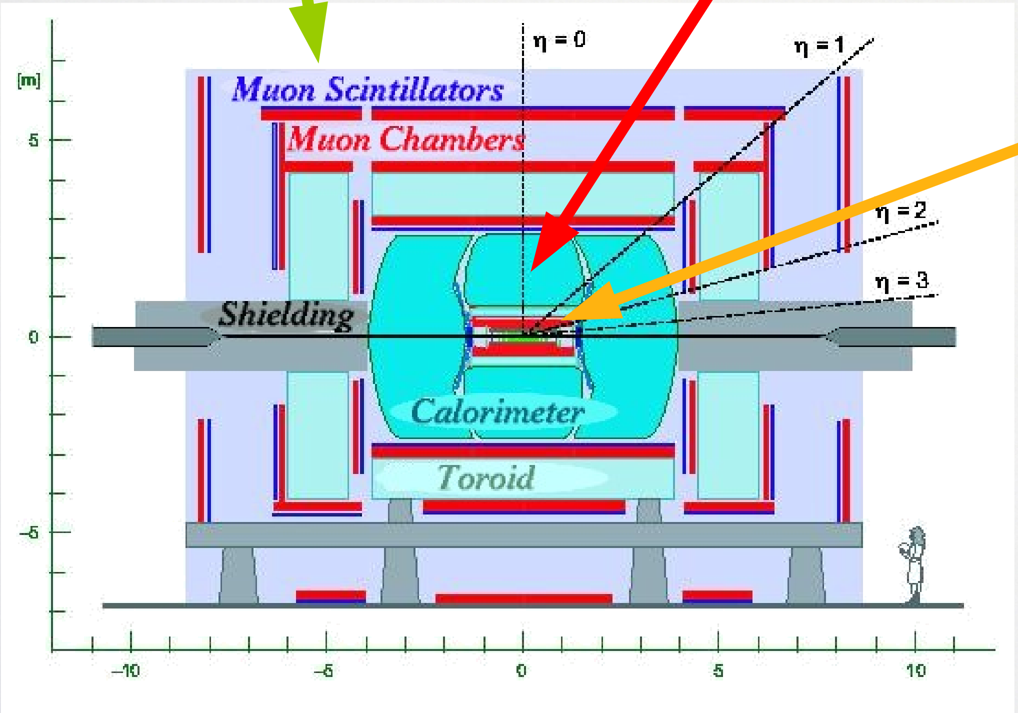
$$\eta = ln(tan\frac{\theta}{2})$$

Experimental apparatus

Muon chamber : identification and momentum measurement of muons.

Calorimeter : identification and energy measurement of jets and electrons.

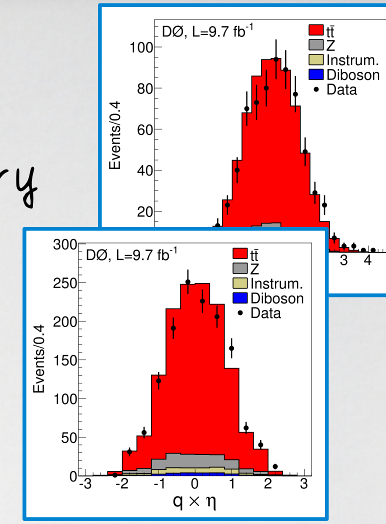
Tracker : detection and momentum measurement of charged particles.



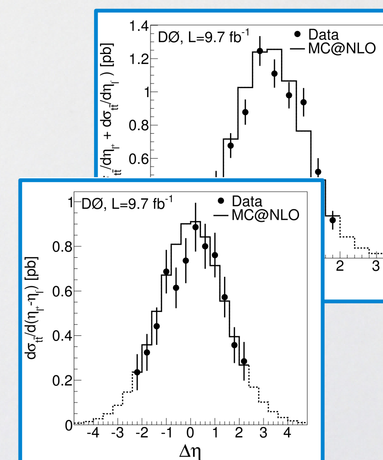
Measurement procedure

1. Event selection

2. Measure the raw (detector) asymmetry



3. Correct for detector effects to the production level



4. Extrapolate to the full phase space

$$A^{extr}_{meas} = A^{corr}_{meas} \times f_{extr}$$

5. Estimate systematic uncertainties

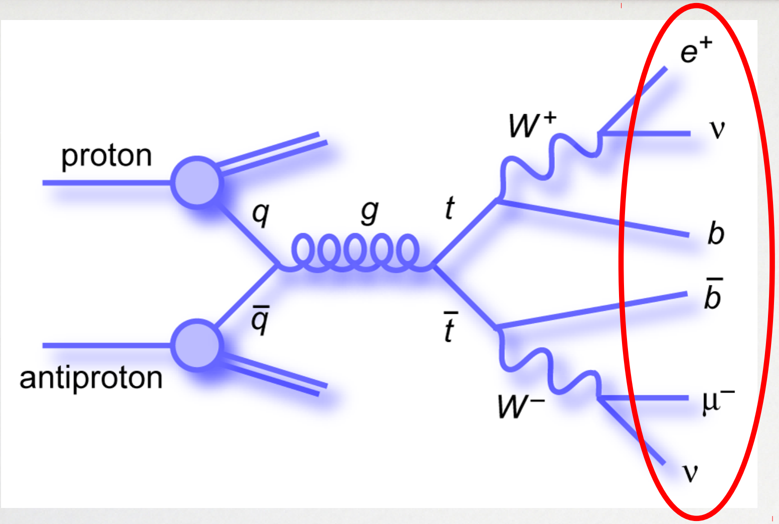
Source	Corrected $A^{\ell}_{\rm FB}$	Corrected $A^{\ell\ell}$	Extrapolated $A^{\ell}_{\rm FB}$	Extrapolated $A^{\ell\ell}$
Object ID	0.54	0.50	0.59	0.60
Background	0.66	0.74	0.72	0.88
Hadronization	0.52	0.62	0.62	0.92
MC statistics	0.19	0.23	0.23	0.37
Total	1.02	1.12	1.14	1.46

6. Results

$$A^{\ell}_{FB} = (.. \pm ..(stat) \pm ..(syst))\%$$

$$A^{\ell\ell} = (.. \pm ..(stat) \pm ..(syst))\%$$

Event selection: dilepton channel

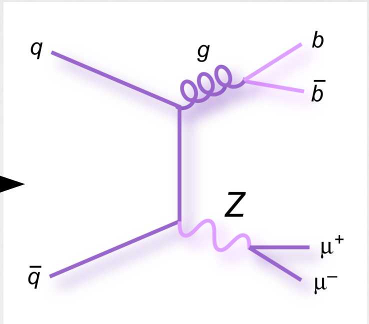


* Two isolated leptons (e or μ) with opposite electric charge.
* High missing E_T due to the 2 neutrinos escaping the detection.
* At least 2 jets and one tagged as a b-jet.

Small rate

Small background :
* Drell-Yan (from MC)
* Instrumental (from data)

W+jets, multijets → fake leptons

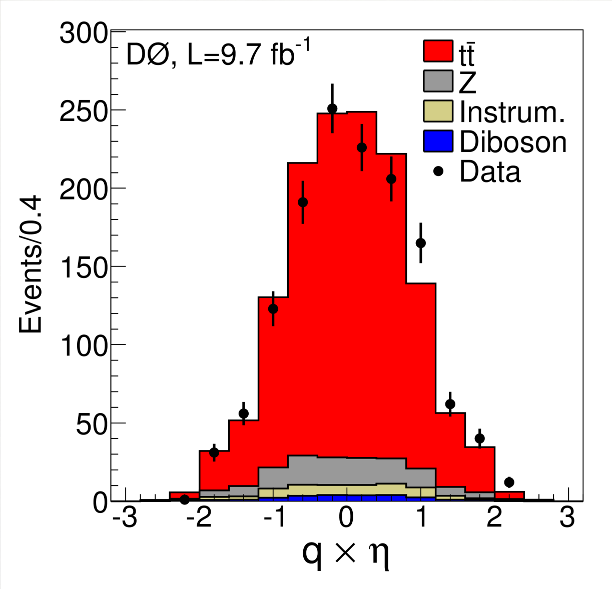


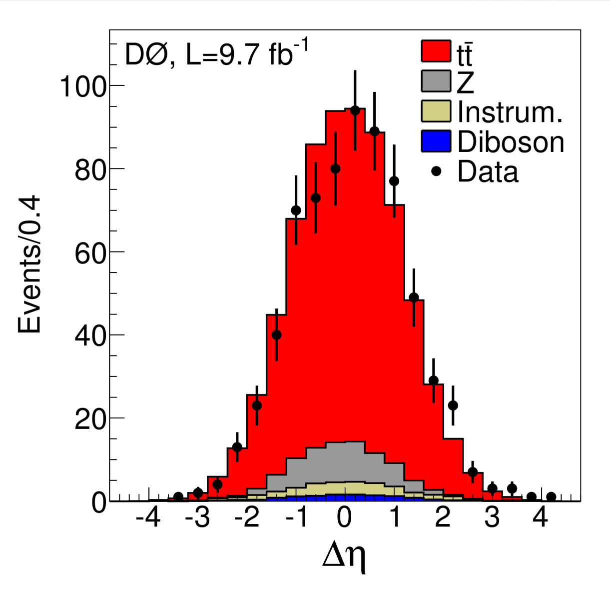
event yield

	$Z \to \ell\ell$	Dibosons	Multijet and W+jets	$t\bar{t} \to \ell\ell jj$	N_{expected}	N_{observed}	$\frac{N_{\text{observed}}}{N_{\text{expected}}}$
ee	$17.2^{+0.6}_{-0.6}$	$2.4^{+0.1}_{-0.1}$	$4.7^{+0.4}_{-0.4}$	$127.8^{+1.4}_{-1.4}$	$152.1^{+1.6}_{-1.6}$	147	0.97 ± 0.08
$e\mu$ 2 jets	$13.7^{+0.5}_{-0.5}$	$3.9^{+0.2}_{-0.2}$	$16.3^{+4.0}_{-4.0}$	$314.7^{+1.1}_{-1.1}$	$348.6^{+4.2}_{-4.2}$	343	0.98 ± 0.05
$e\mu$ 1 jet	$8.7^{+0.6}_{-0.6}$	$3.4^{+0.2}_{-0.2}$	$2.9^{+1.7}_{-1.7}$	$61.7^{+0.5}_{-0.5}$	$76.7^{+1.9}_{-1.9}$	78	1.02 ± 0.12
$\mu\mu$	$17.5^{+0.6}_{-0.6}$	$1.9^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$97.7^{+0.6}_{-0.6}$	$117.1^{+0.8}_{-0.8}$	114	0.97 ± 0.09

full dataset 9.7 fb^{-1}

Raw measurement and corrections



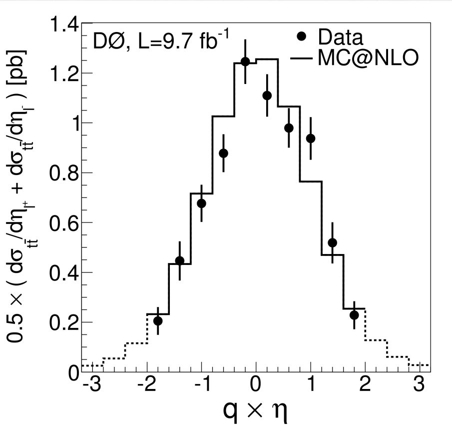


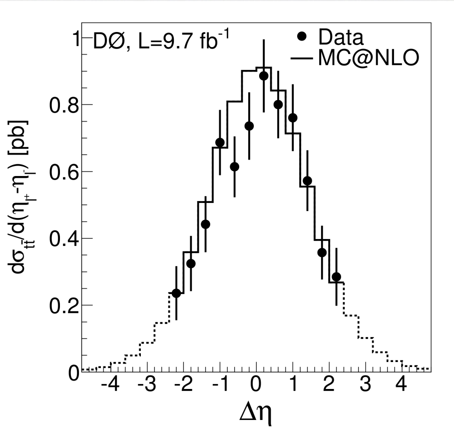
Subtract in each bin from data the estimated background and measure the raw asymmetry.

Restriction of the visible phase space to $|\Delta\eta| < 2.4$, $|q \times \eta| < 2.0$ in order to avoid large uncertainty due to selection efficiency correction.

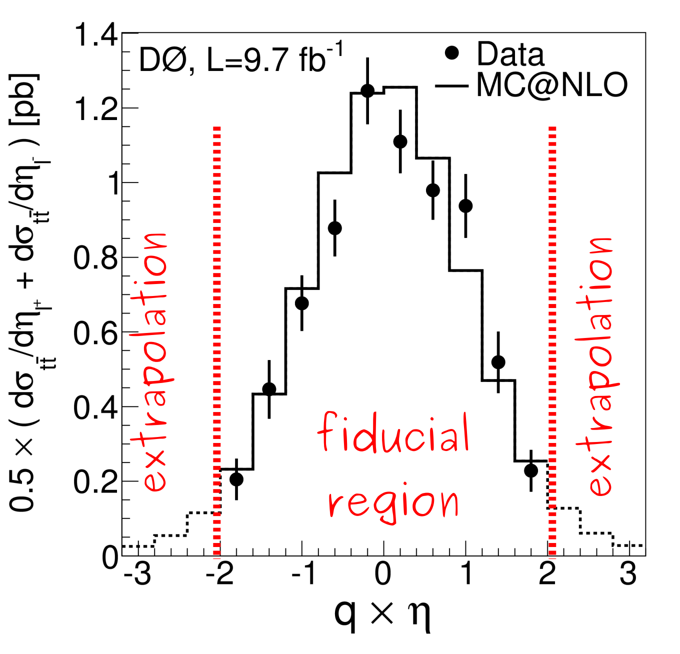
Correct in each bin for selection efficiency using MC informations to go back to the production level (resolution effects are negligible)

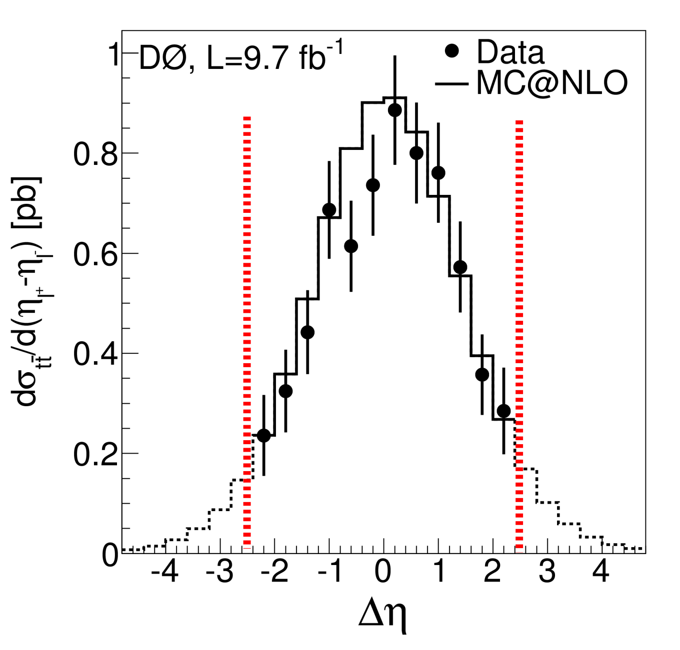
$$N^i_{corr} = N^i_{obs} \times \epsilon^i_{rec} \qquad \epsilon^i_{rec} = \frac{N^i_{partonic}}{N^i_{rec}}$$





Extrapolation to the full phase space





To compare with the predictions and other measurements → extrapolation to the full phase space.

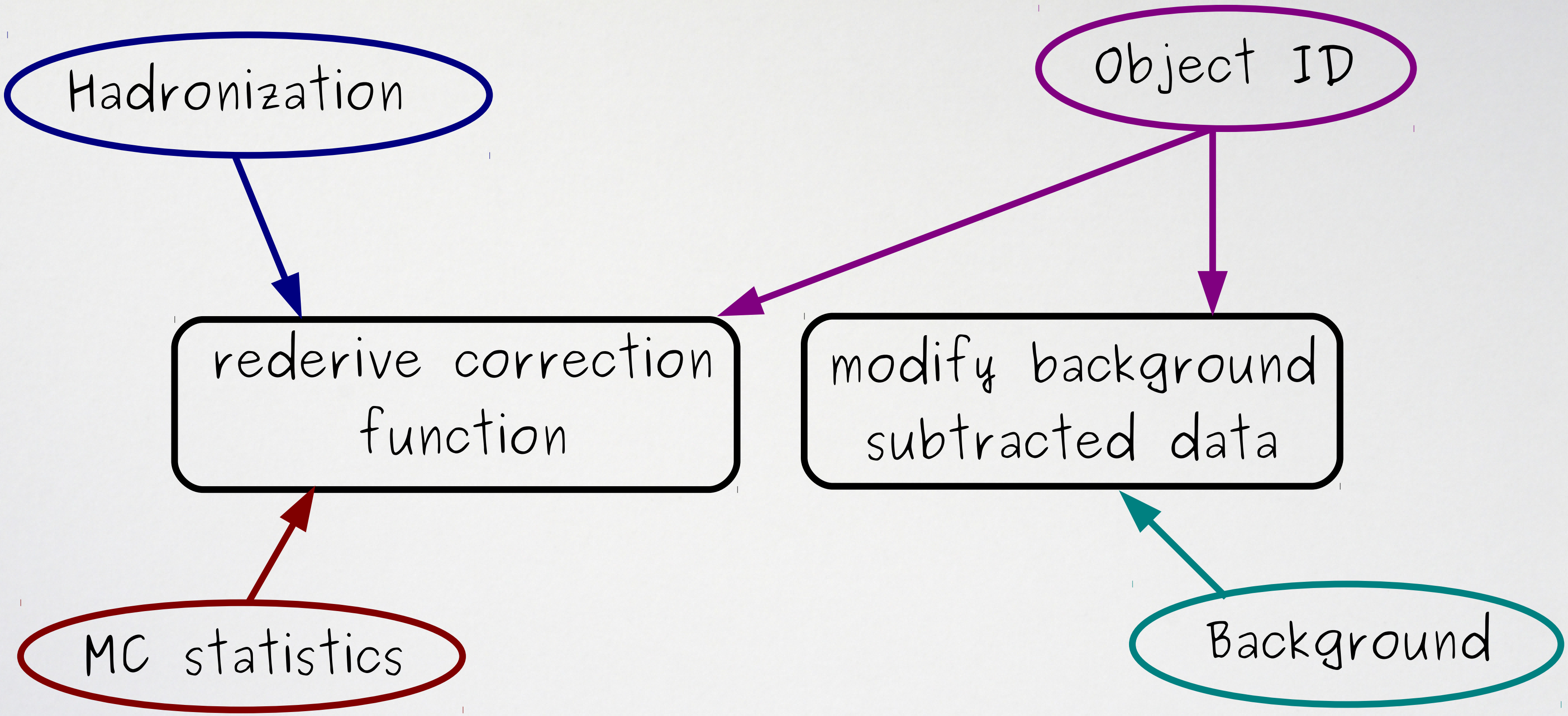
$$A^{extr}_{meas} = A^{corr}_{meas} \times f_{extr}$$

$$f_{extr} = \frac{A^{full\ acceptance}_{\mathrm{MC@NLO}\ t\bar{t}}}{A^{fiducial}_{\mathrm{MC@NLO}\ t\bar{t}}}$$

Assuming SM through MC@NLO.

Validity of the extrapolation was checked using new-physics models (axigluons: Phys. Rev. D 87, 034039 (2013))

Systematic uncertainties



[%]	Corrected A^{ℓ}_{FB}	Corrected $A^{\ell\ell}$	Extrapolated A^{ℓ}_{FB}	Extrapolated $A^{\ell\ell}$
Source				
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MC statistics	0.19	0.23	0.23	0.37
Total	1.02	1.12	1.14	1.46

Results

Combination of the measurements from all the channels using the BLUE method

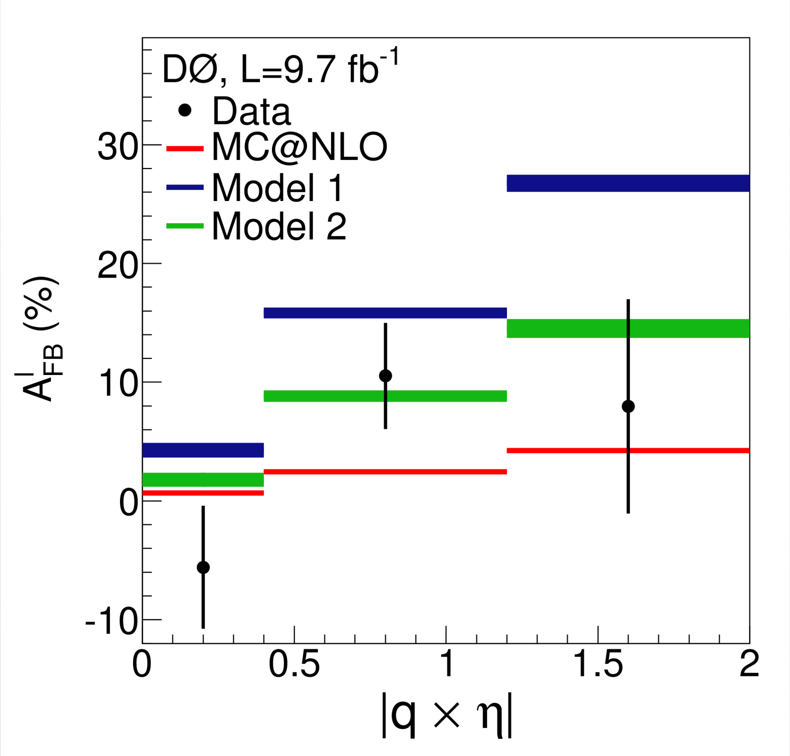
$$A^{\ell}_{FB} = (4.4 \pm 3.7(stat) \pm 1.1(syst))\%$$

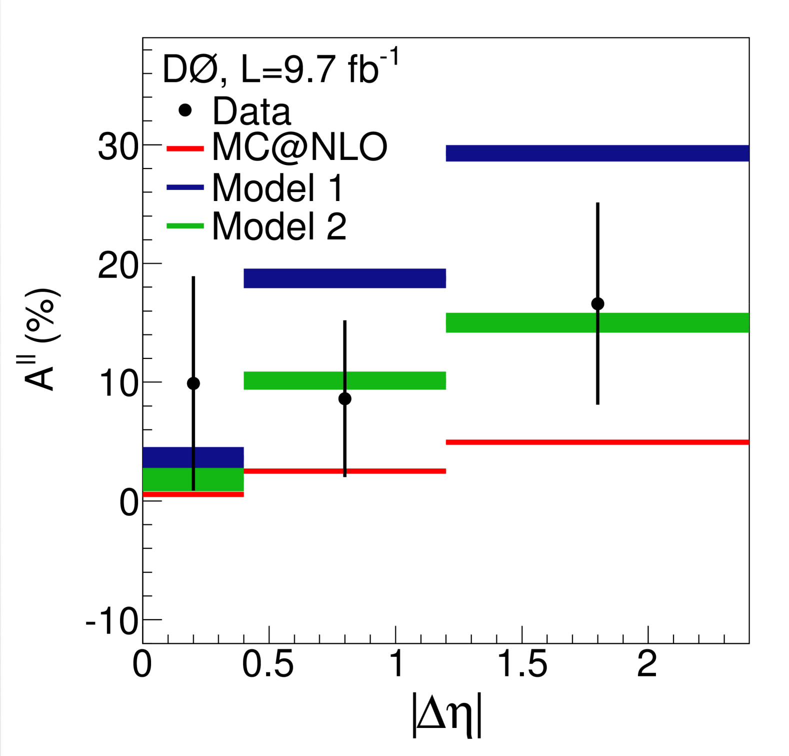
$$A^{\ell\ell} = (12.3 \pm 5.4(stat) \pm 1.5(syst))\%$$

$$A^{\ell}_{FB}(SM) = (3.8 \pm 0.3)\%$$

$$A^{\ell\ell}(SM) = (4.8 \pm 0.4)\%$$

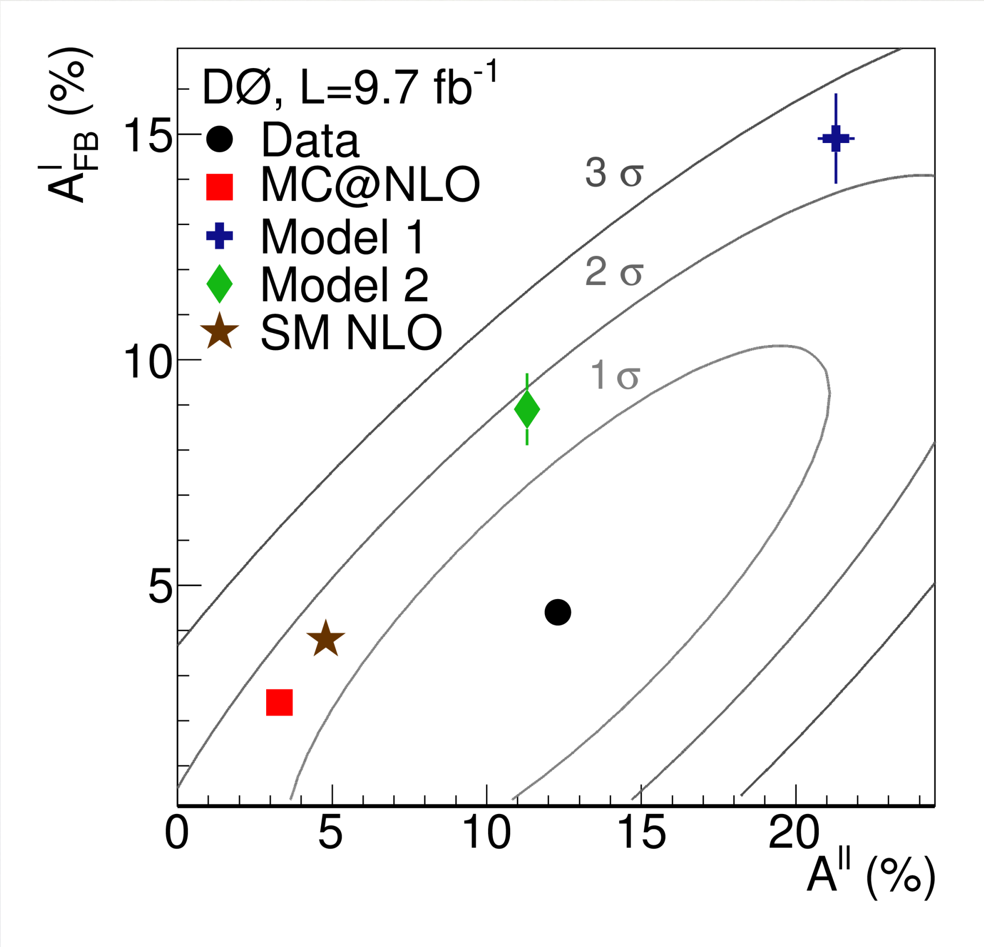
Bernreuther & Si PRD 86 034026 (2012)





Phys. Rev. D 88, 112002 (2013)

Results



Model 1 and 2 are axigluon models.

$$A^{\ell}_{FB}/A^{\ell\ell} = 0.36 \pm 0.20$$

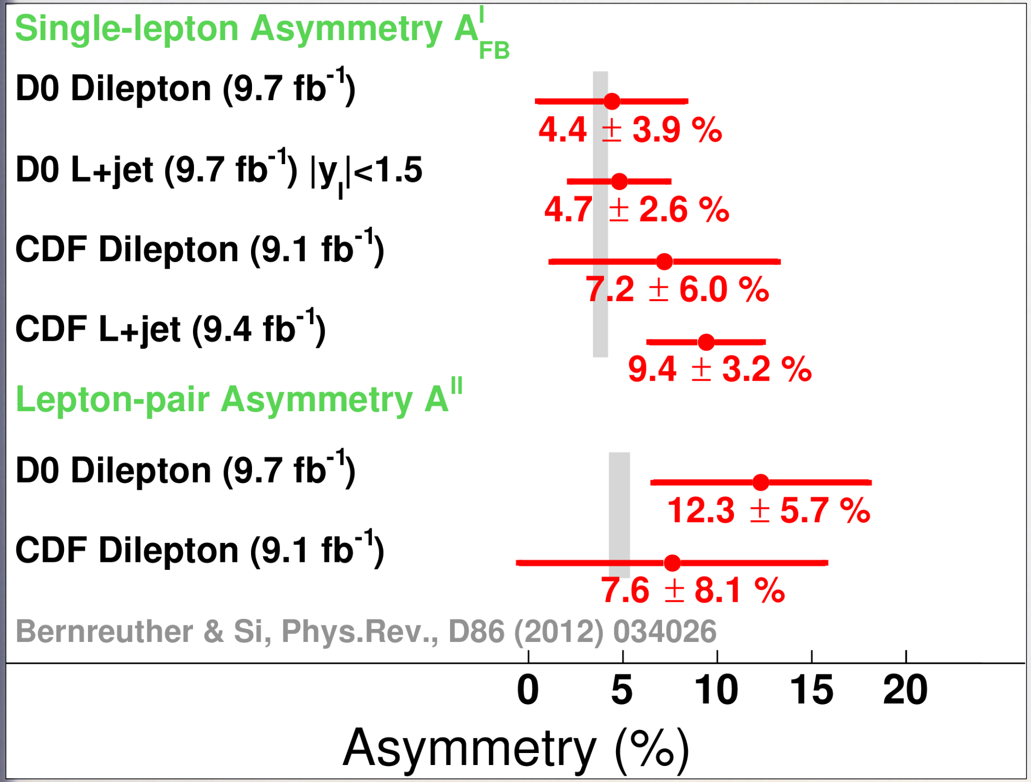
$$A^{\ell}_{FB}/A^{\ell\ell}(SM) = 0.79 \pm 0.10$$

We measured the ratio of the two asymmetries
→ better sensitivity due to uncertainty cancellation (correlated asymmetries)

Conclusion

Measurement of the leptonic $t\bar{t}$ asymmetries in the dilepton channel at DØ with the full Tevatron statistics.

⇒ Agreement with the SM predictions and with the other measurements from CDF and DØ.



Next step:

Combination of the leptonic asymmetries from CDF and DØ.


MERCI

Additional materials

Results per channel

	Corrected	Extrapolated	Prediction
A^{ℓ}_{FB}			
ee	$6.8 \pm 8.5 \pm 1.3$		
$e\mu$ 2 jets	$5.0 \pm 4.6 \pm 1.0$		
$e\mu$ 1 jet	$-0.1 \pm 10.4 \pm 2.5$		
$\mu\mu$	$0.8 \pm 8.5 \pm 1.4$		
Combined	$4.1 \pm 3.5 \pm 1.0$	$4.4 \pm 3.7 \pm 1.1$	3.8 ± 0.3
$A^{\ell\ell}$			
ee	$16.4 \pm 10.4 \pm 1.6$		
$e\mu$ 2 jets	$11.1 \pm 6.3 \pm 1.3$		
$e\mu$ 1 jet	$-2.1 \pm 15.7 \pm 3.4$		
$\mu\mu$	$7.4 \pm 11.7 \pm 1.4$		
Combined	$10.5 \pm 4.7 \pm 1.1$	$12.3 \pm 5.4 \pm 1.5$	4.8 ± 0.4

$f_{extr} = 1.07$ for A^{ℓ}_{FB} and 1.17 for $A^{\ell\ell}$

Event selection

* Vertex: $|z|<60$ cm, at least 3 tracks attached
* Electrons: $p_T>15$ GeV, $|\eta_{det}|<1.1$ and $1.5<|\eta_{det}|<2.5$
* Muons: $15<p_T<200$ GeV, $|\eta_{det}|<2.0$
* DeltaR$(e,\mu)>0.3$
* Jets: $p_T>20$ GeV

* Final selection: optimized to minimize the expected statistical uncertainty on the asymmetries
  - Topological cut: Ht $(e\mu)$ and METsig $(ee, \mu\mu)$
  - B-jet identification discriminant

Event selection

pothesis to the two jets of largest p_T. We use different cutoffs of the MVA discriminant variable, corresponding to b-jet efficiencies of 84% in $e\mu$ 2 jets, 80% in ee, 78% in $\mu\mu$, and 60% in $e\mu$ 1-jet events, with background misidentification efficiencies, respectively, of 23%, 12%, 7%, and 4%.

After the entire selection:

S/B: 5.3 (ee), 9.3 (eμ 2 jets), 4.1 (eμ 1 jet), 5 (μμ)

$S/\sqrt{S+B}$: 10.4 (ee), 16.7 (eμ 2 jets), 7.0 (eμ 1 jet), 9.0 (μμ)

Fake electron estimation

Matrix method

$$n_{\mathrm{loose}} = n_e/\varepsilon_e + n_f/f_e,$$

$$n_{\mathrm{tight}} = n_e + n_f,$$

nber of true electron

Fake electron misid efficiency

nber of fake electron

true electron selection efficiency

EC parts of the calorimeter. Typical values of ε_e are 0.7–0.8 in the CC and 0.65–0.75 in the EC. Values of f_e are 0.005–0.010 in the CC, and 0.005–0.020 in the EC.

Fake muon estimation

The number of fake events in the muonic channels is taken as the number of event with two same sign leptons passing the final selection.

N.B.: If the charge of the μ is misid, it means that the muon track is not the correct one. The muon p_T is measured using the track => charge misid → bad momentum measurement. Cannot use the Z peak.

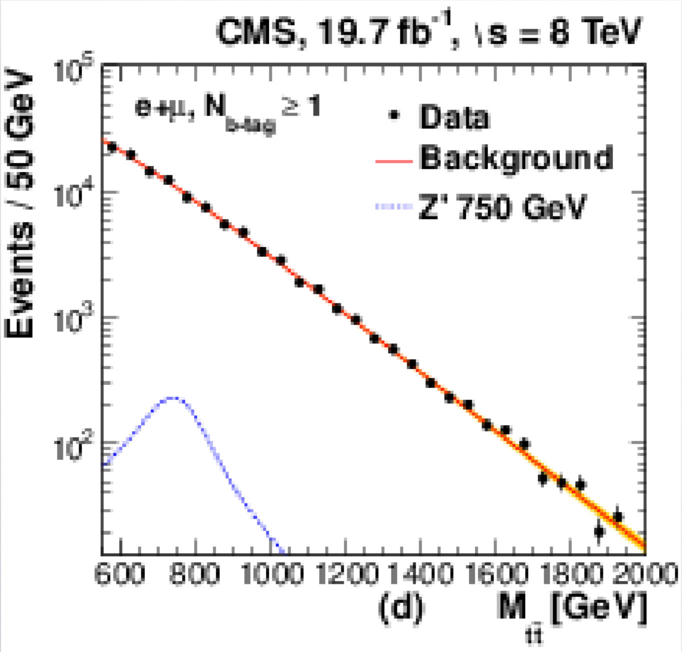
Axigluon constraints

* Dijet and top pair production.
* LHC charge asymmetry.
* Electroweak precision observable.

[Bai et al., JHEP1103 (2011) 003]

[Haisch, Westhoff, JHEP1108 (2011) 088]

[Gresham, Shelton, Zurek, JHEP1303 (2013) 008]



CMS M(ttbar) measurement

Axigluon constraints

AXIGLUON SURVIVORS

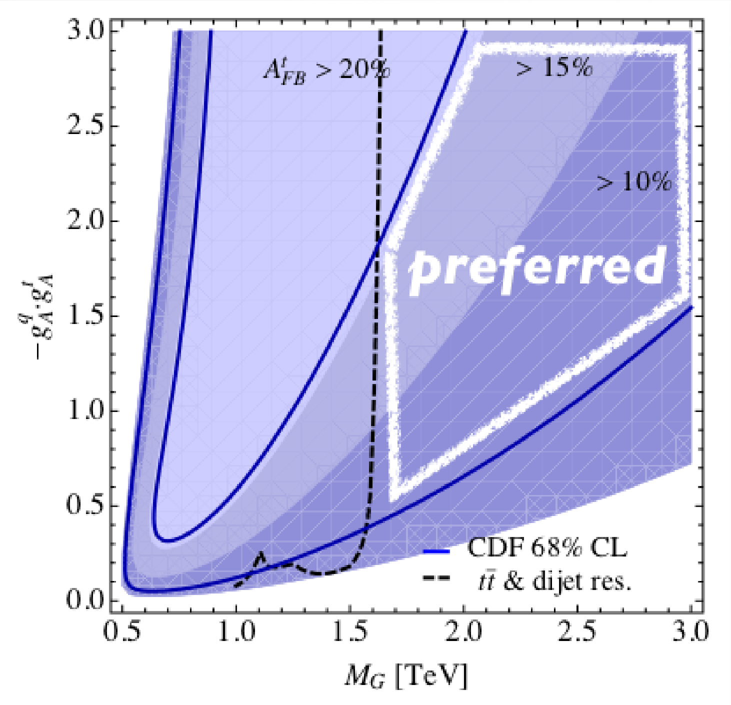
Heavy, flavor-sensitive:

$$M_G \approx 2\,\mathrm{TeV}$$
$$g_A^q = -g_A^t \sim 1.0\, g_s$$

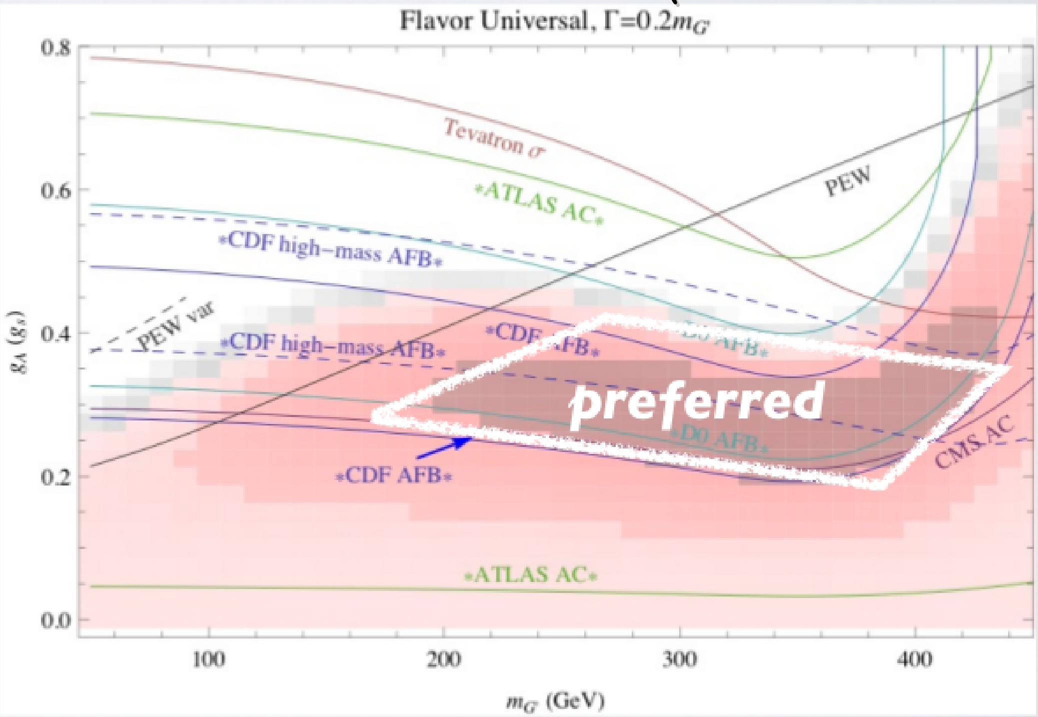
Light, broad, flavor-universal:

$$200 \lesssim M_G \lesssim 450\,\mathrm{GeV}$$
$$g_A^q = g_A^t \sim 0.3\, g_s$$

Susanne Westhoff
TOP2013, Germany



[Haisch, Westhoff, JHEP1108 (2011) 088 updated]

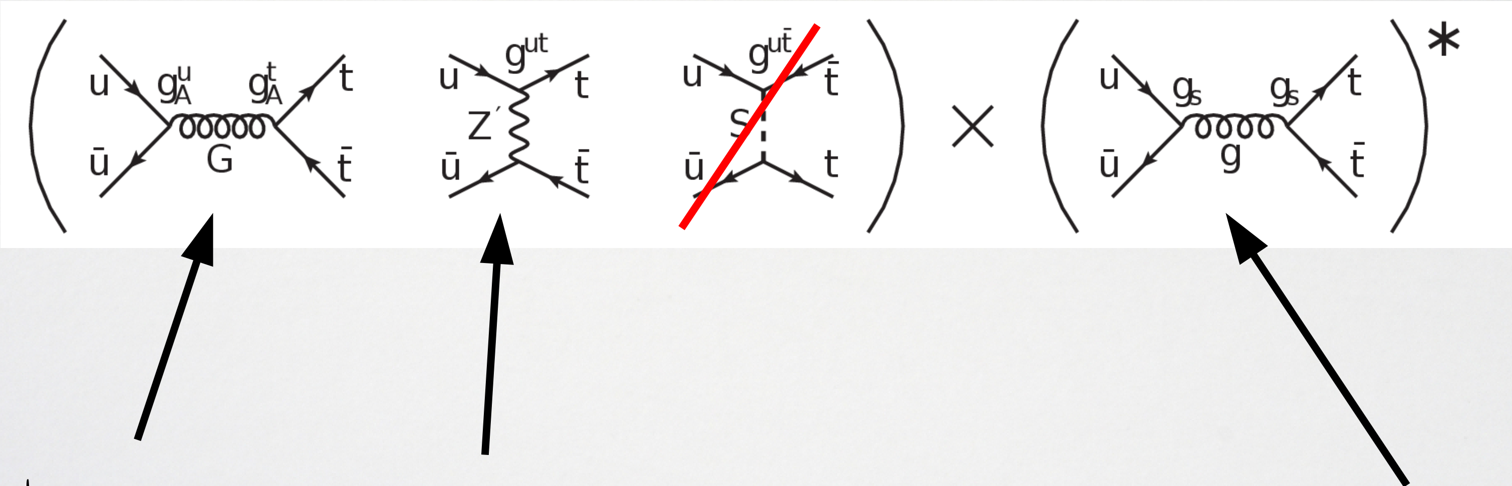


[Gresham, Shelton, Zurek, JHEP1303 (2013) 008]

Physics beyond the Standard Model ?

Some new physics models could explain the deviations observed at the Tevatron

tree level interferences with SM



''<u>axigluon</u>'' : massive color octet with axial-vector couplings to quark in the s-channel

<u>Z'</u> : vector boson with flavor changing couplings in the t-channel

SM model $t\bar{t}$ production

Let's focus on the axigluon model.

[Frampton, Glashow, PLB190 (1987) 157]

Axigluon model

Contribution to $t\bar{t}$ production from SM gluon / axigluon interference :

$$\sigma_a^{INT} \approx g_s^2 \frac{g_A^q g_A^t}{M_{t\bar{t}}^2 - M_G^2}$$

QCD coupling constant

mass of the $t\bar{t}$ pair

axigluon mass

Axial-vector coupling to light (q) and top (t) quarks

* We need :

$$\sigma_a^{INT} > 0$$

to observe a positive contribution to the asymmetry

$$M_G > M_{t\bar{t}} \; , \; g_A^q \cdot g_A^t < 0$$

[Frampton, Shu, Wang, PLB683 (2010) 294]

$$M_G \leq M_{t\bar{t}} \; , \; g_A^q \cdot g_A^t > 0$$

[Tavares, Schmaltz, PRD84 (2011) 054008]

Axigluon model

Contribution to the $t\bar{t}$ production from axigluon self-interf :

No contribution to the asymmetry but it constraints the model.

$$\sigma_s^{NP} \approx (g_A^q)^2 (g_A^t)^2 \frac{M_{t\bar{t}}^2}{(M_{t\bar{t}}^2 - M_G^2)^2}$$

→ σs(NP) contribution should be small to respect the agreement between the measured and predicted $t\bar{t}$ cross-section.

<u>e.g.</u> : if the axigluon mass is close to the $t\bar{t}$ resonance ($M_G \sim M_{ttbar}$) → couplings should be very small !

Also, the width of axigluon should be large not to be seen in the $t\bar{t}$ production spectrum.