New Physics in Top Pair Production: Hints and Constraints

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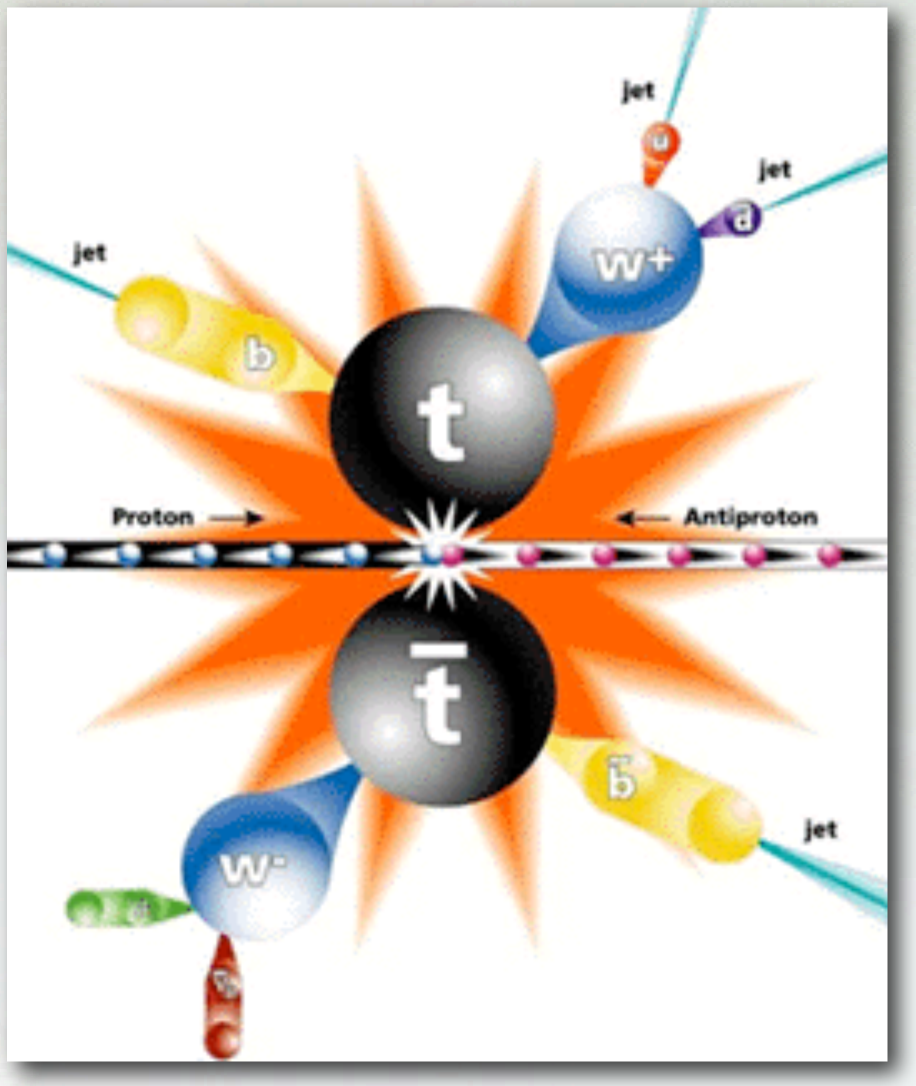
based on work with
Juan Antonio Aguilar Saavedra

arXiv:1103.2765 (JHEP)
arXiv:1104.1385 (PLB)

Outline

- New physics contributing to $t\bar{t}$ and tt production
- Forward-backward asymmetry @ Tevatron
- $t\bar{t}$ tail @ LHC
- Like-sign constraints

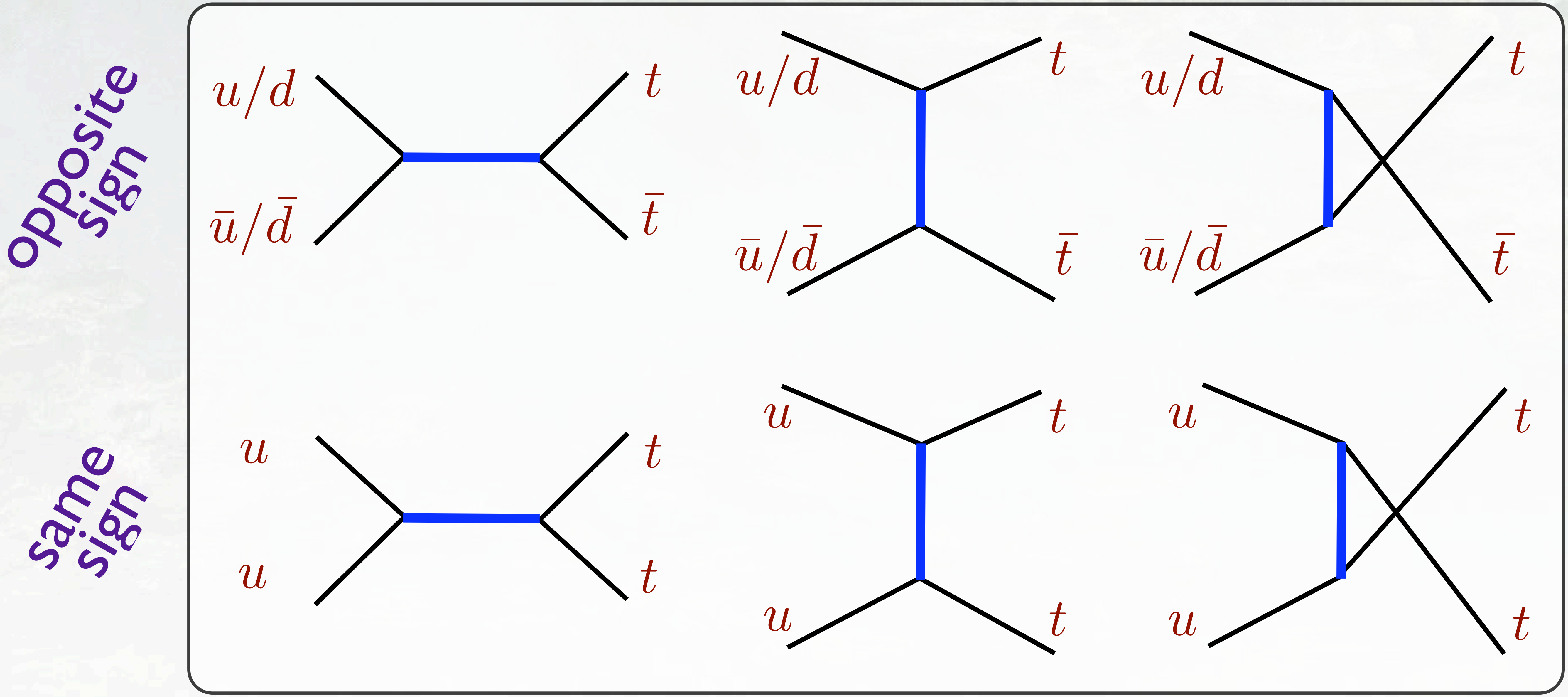


Top pair production

- Total Cross Section (shape) ✓
- FB Asymmetry (shape) ??!! ☺

Large Effects → New Bosons at Tree Level

s channel | t channel | u channel



Opposite-sign tops

Vectors	Rep	Channel
$\mathcal{B}$	$(1,1)_0$	s,t
$\mathcal{W}$	$(1,3)_0$	s,t
$\mathcal{B}^1$	$(1,1)_1$	t
$\mathcal{G}$	$(8,1)_0$	s,t
$\mathcal{H}$	$(8,3)_0$	s,t
$\mathcal{G}^1$	$(8,1)_1$	t
$\mathcal{Q}^1$	$(3,2)_{\frac{1}{6}}$	u
$\mathcal{Q}^5$	$(3,2)_{-\frac{5}{6}}$	u
$\mathcal{Y}^1$	$(\bar{6},2)_{\frac{1}{6}}$	u
$\mathcal{Y}^5$	$(\bar{6},2)_{-\frac{5}{6}}$	u

Scalars	Rep	Channel
ϕ	$(1,2)_{-\frac{1}{2}}$	s,t
Φ	$(8,2)_{-\frac{1}{2}}$	s,t
ω^1	$(3,1)_{-\frac{1}{3}}$	u
Ω^1	$(\bar{6},1)_{-\frac{1}{3}}$	u
ω^4	$(3,1)_{-\frac{4}{3}}$	u
Ω^4	$(\bar{6},1)_{-\frac{4}{3}}$	u
σ	$(3,3)_{-\frac{1}{3}}$	u
Σ	$(\bar{6},3)_{-\frac{1}{3}}$	u

Same-sign tops

Vectors	Rep	Channel
$\mathcal{B}$	$(1,1)_0$	t
$\mathcal{W}$	$(1,3)_0$	t
$\mathcal{G}$	$(8,1)_0$	t
$\mathcal{H}$	$(8,3)_0$	t
$\mathcal{Q}^5$	$(3,2)_{-\frac{5}{6}}$	s
$\mathcal{Y}^5$	$(\bar{6},2)_{-\frac{5}{6}}$	s

Scalars	Rep	Channel
ϕ	$(1,2)_{-\frac{1}{2}}$	t
Φ	$(8,2)_{-\frac{1}{2}}$	t
Ω^4	$(\bar{6},1)_{-\frac{4}{3}}$	s
Σ	$(\bar{6},3)_{-\frac{1}{3}}$	s

Opposite sign tops @ Tevatron

$$\sigma_t = \sigma^F + \sigma^B \qquad = \sigma_t^{SM}$$

(CDF)

$$A_{FB} = \frac{\sigma^F - \sigma^B}{\sigma^F + \sigma^B} \qquad \neq A_{FB}^{SM}$$

$$\sigma^{F,B} = \sigma_{\rm SM}^{F,B} + \sigma_{\rm int}^{F,B} + \sigma_{\rm new}^{F,B}$$

$$\sim \frac{g_{\rm new}^2}{M_{new}^2}$$

$$\sim \frac{g_{\rm new}^4}{M_{new}^4}$$

Opposite sign tops @ Tevatron

$$\sigma_t = \sigma^F + \sigma^B \qquad = \sigma_t^{SM}$$

(CDF)

$$A_{FB} = \frac{\sigma^F - \sigma^B}{\sigma^F + \sigma^B} \qquad \neq A_{FB}^{SM}$$

$$\sigma^{F,B} = \sigma_{\text{SM}}^{F,B} + \sigma_{\text{int}}^{F,B} + \sigma_{\text{new}}^{F,B}$$

New physics must satisfy one of the following eqs.

- ★ $\sigma_{\text{int}}^F + \sigma_{\text{int}}^B = 0$
- ★ $\sigma_{\text{int}}^F + \sigma_{\text{int}}^B = -(\sigma_{\text{new}}^F + \sigma_{\text{new}}^B)$

Opposite sign tops @ Tevatron

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(CDF)
$$A_{FB} = \frac{\sigma^F - \sigma^B}{\sigma^F + \sigma^B} \qquad \neq A_{FB}^{SM}$$

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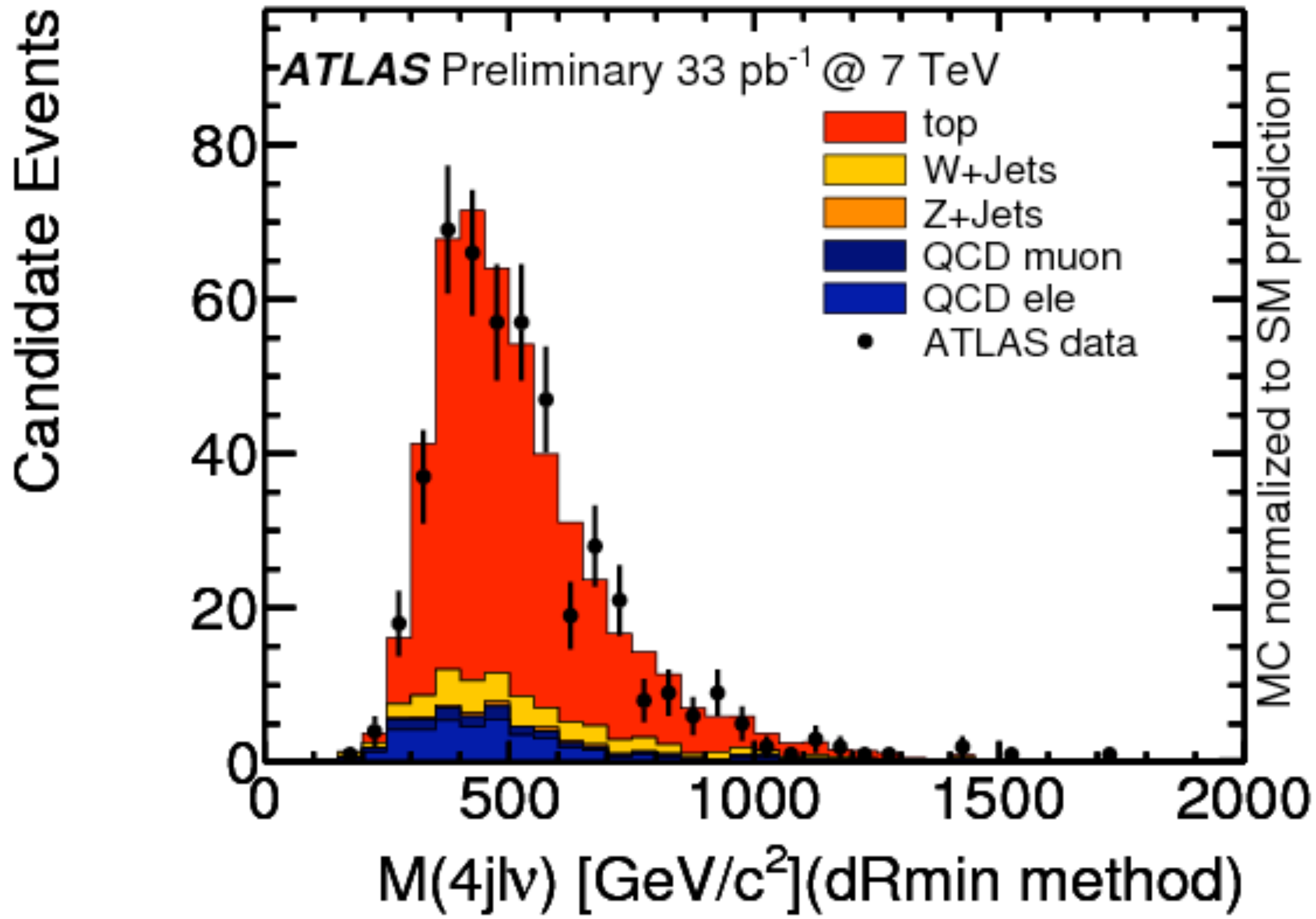
New physics must satisfy one of the following eqs.

- ★ $\sigma_{\rm int}^F + \sigma_{\rm int}^B = 0$ E.g. $\mathcal{G}$ axial
- ★ $\sigma_{\rm int}^F + \sigma_{\rm int}^B = -(\sigma_{\rm new}^F + \sigma_{\rm new}^B)$ At given $m_{t\bar{t}}$

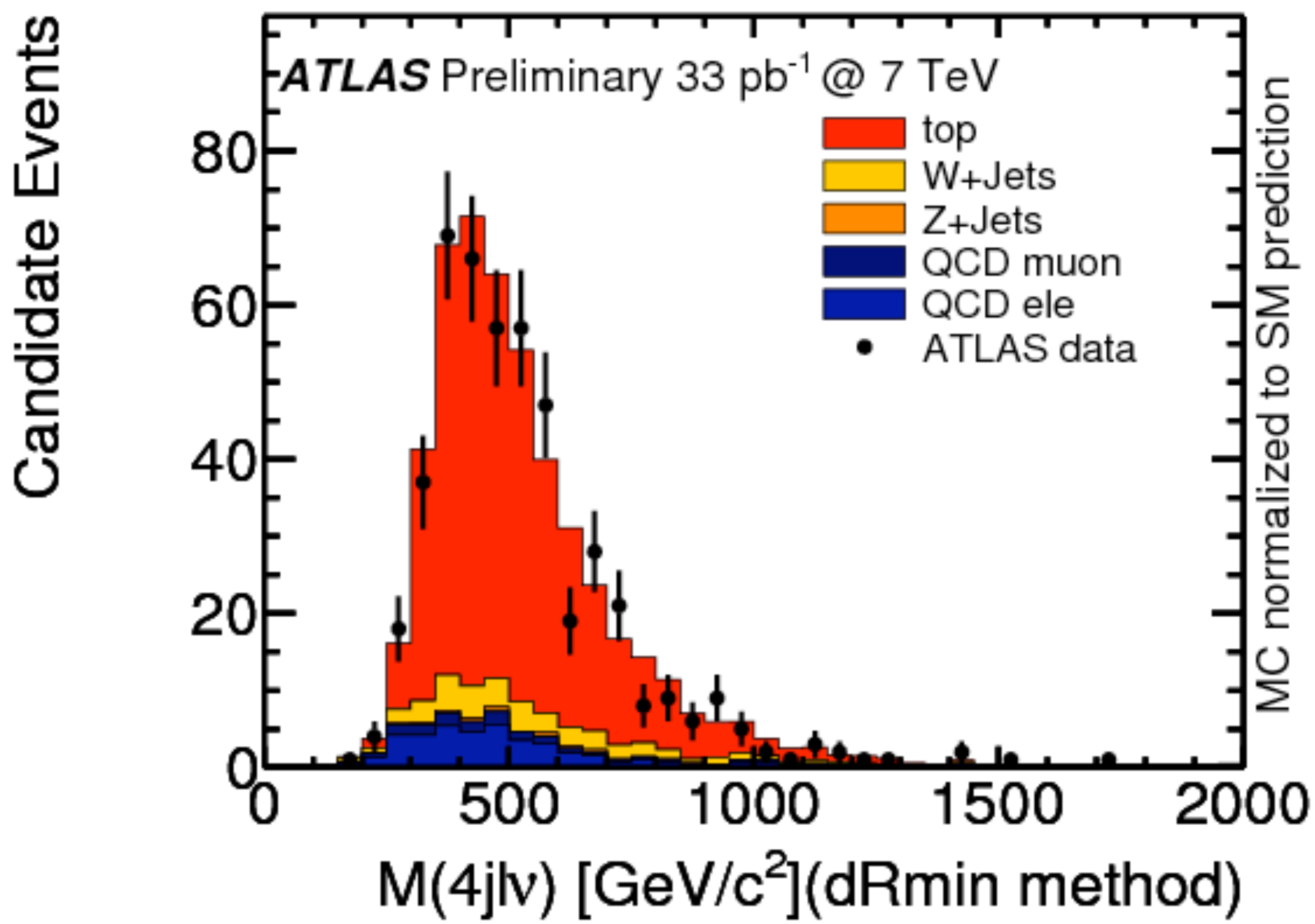
Large coupling/mass ➡ Large effects elsewhere

$t\bar{t}$ Tail @ LHC



If A_{FB} is due to new physics, we should notice it in the cross section distribution at large $m_{t\bar{t}}$

$t\bar{t}$ Tail @ LHC



If A_{FB} is due to new physics, we should notice it in the cross section distribution at large $m_{t\bar{t}}$

Talk by J.A. Aguilar-Saavedra on Friday

Like-sign constraints

$uu \longrightarrow tt$ very small in SM $\Rightarrow$ $\sigma(tt) = \sigma_{\rm new}(tt)$

(no interference)

$\sigma(tt + \overline{tt}) < 0.49\,{\rm pb}$ CDF (6.1 fb^{-1})

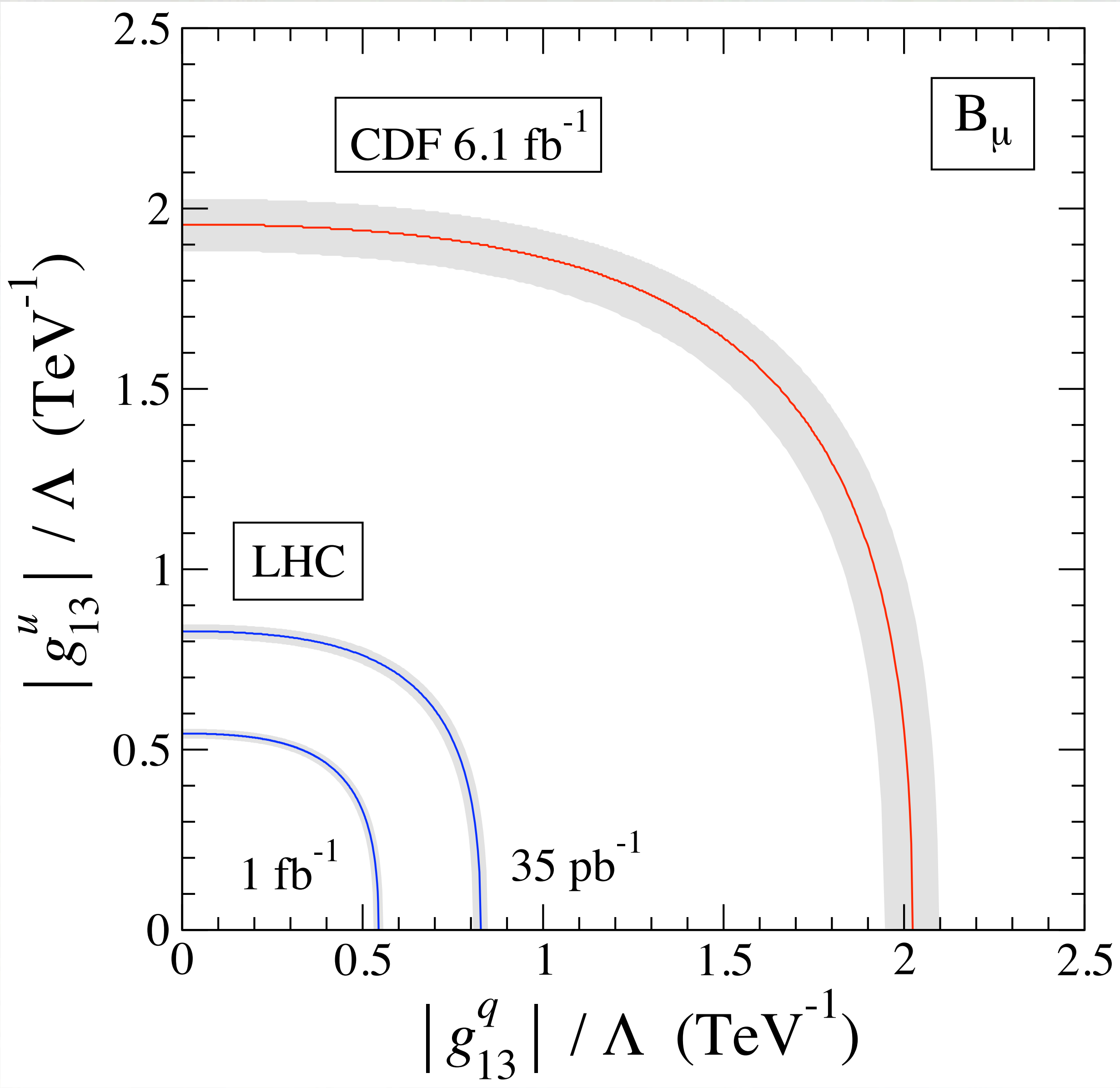
$\sigma(tt) < 7.5\,{\rm pb}$ LHC (35 pb^{-1})

$\sigma(tt) < 1.4\,{\rm pb}$ LHC (1 fb^{-1})

estimated

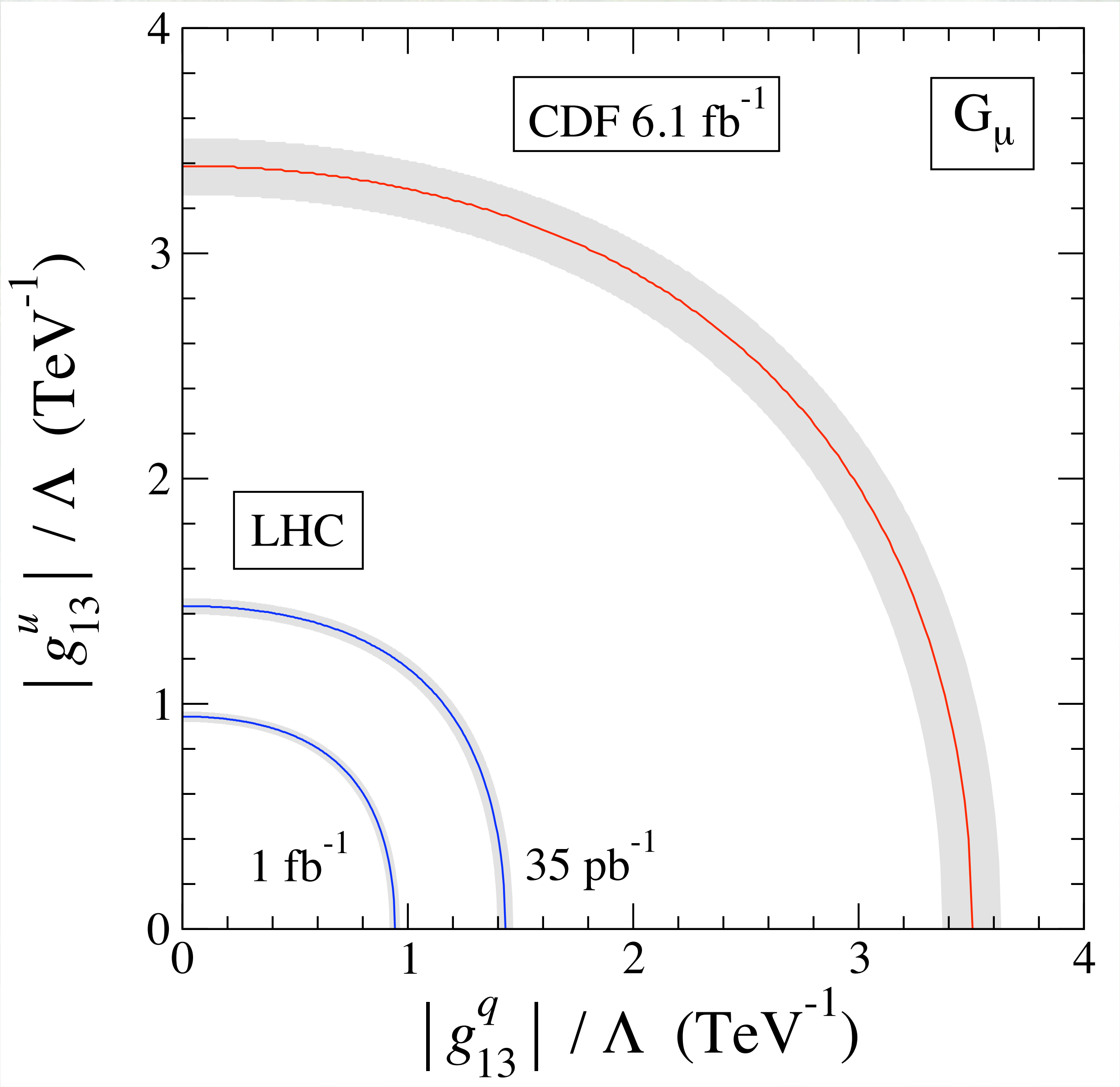
Limits on Couplings/Masses (heavy)

Z' (t-channel)



$$-\mathcal{B}_\mu \left(g^q_{13} \bar{q}_{L1} \gamma^\mu q_{L3} + g^u_{13} \bar{u}_{R1} \gamma^\mu u_{R3} \right)$$

Gluon' (t-channel)



$$-\mathcal{G}^a_\mu \left(g^q_{13} \bar{q}_{L1} \gamma^\mu \frac{\lambda^a}{2} q_{L3} + g^u_{13} \bar{u}_{R1} \gamma^\mu \frac{\lambda^a}{2} q_{L3} u_{R3} \right)$$

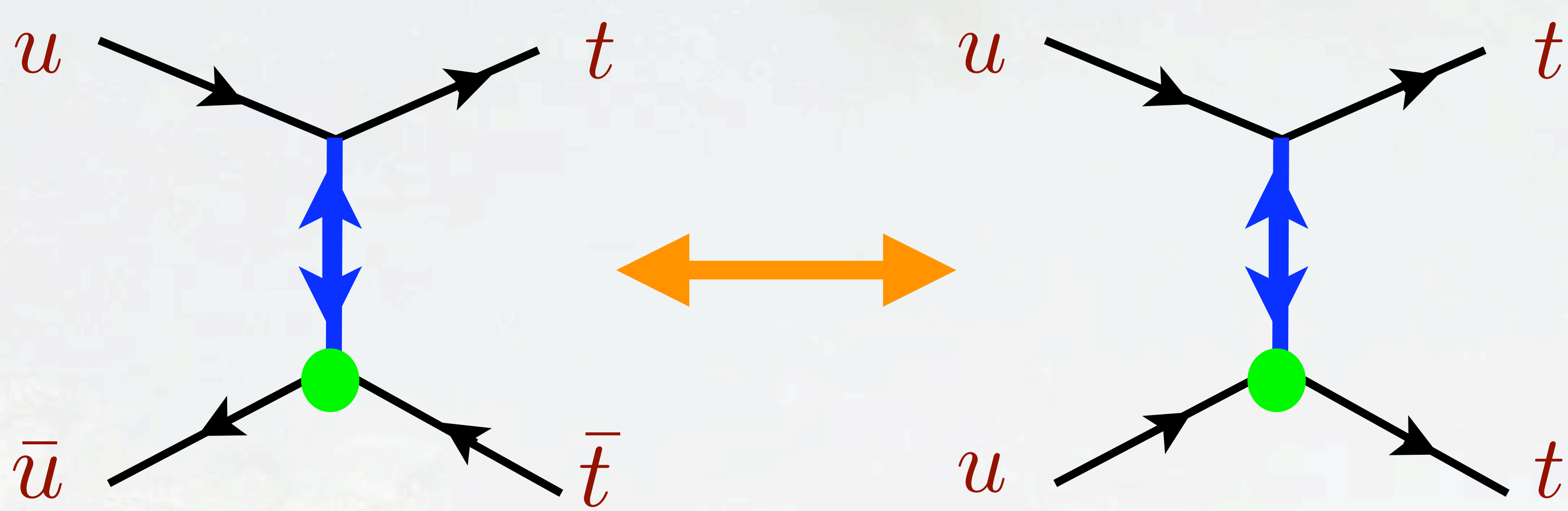
Limits on Couplings/Masses (heavy)

			CDF limit	LHC expected 35 pb^{-1}	LHC expected 1 fb^{-1}	
$\mathcal{W}_\mu$	$\lvert g_{13}\rvert/\Lambda$	$<$	$2.02^{+0.07}_{-0.08}$	$0.827^{+0.020}_{-0.021}$	$0.544^{+0.013}_{-0.014}$	TeV^{-1}
$\mathcal{H}_\mu$	$\lvert g_{13}\rvert/\Lambda$	$<$	$3.50^{+0.13}_{-0.13}$	$1.433^{+0.034}_{-0.037}$	$0.942^{+0.022}_{-0.024}$	TeV^{-1}
$\mathcal{Q}^5_\mu$	$\lvert g_{11}g_{33}\rvert/\Lambda^2$	$<$	$3.72^{+0.26}_{-0.27}$	$0.716^{+0.038}_{-0.039}$	$0.310^{+0.017}_{-0.017}$	TeV^{-2}
$\mathcal{Y}^5_\mu$	$\lvert g_{11}g_{33}\rvert/\Lambda^2$	$<$	$8.6^{+0.7}_{-0.9}$	$1.32^{+0.06}_{-0.06}$	$0.568^{+0.025}_{-0.027}$	TeV^{-2}
ϕ	$\lvert g^u_{13}g^u_{31}\rvert/\Lambda^2$	$<$	$11.2^{+0.8}_{-0.8}$	$1.94^{+0.09}_{-0.10}$	$0.838^{+0.040}_{-0.043}$	TeV^{-2}
Φ	$\lvert g^u_{13}g^u_{31}\rvert/\Lambda^2$	$<$	$21.3^{+1.6}_{-1.6}$	$3.67^{+0.18}_{-0.19}$	$1.59^{+0.08}_{-0.08}$	TeV^{-2}
Ω^4	$\lvert g_{11}g_{33}\rvert/\Lambda^2$	$<$	$3.79^{+0.27}_{-0.28}$	$0.684^{+0.033}_{-0.035}$	$0.296^{+0.014}_{-0.015}$	TeV^{-2}
Σ	$\lvert g_{11}g_{33}\rvert/\Lambda^2$	$<$	$2.04^{+0.15}_{-0.15}$	$0.342^{+0.017}_{-0.017}$	$0.148^{+0.007}_{-0.008}$	TeV^{-2}

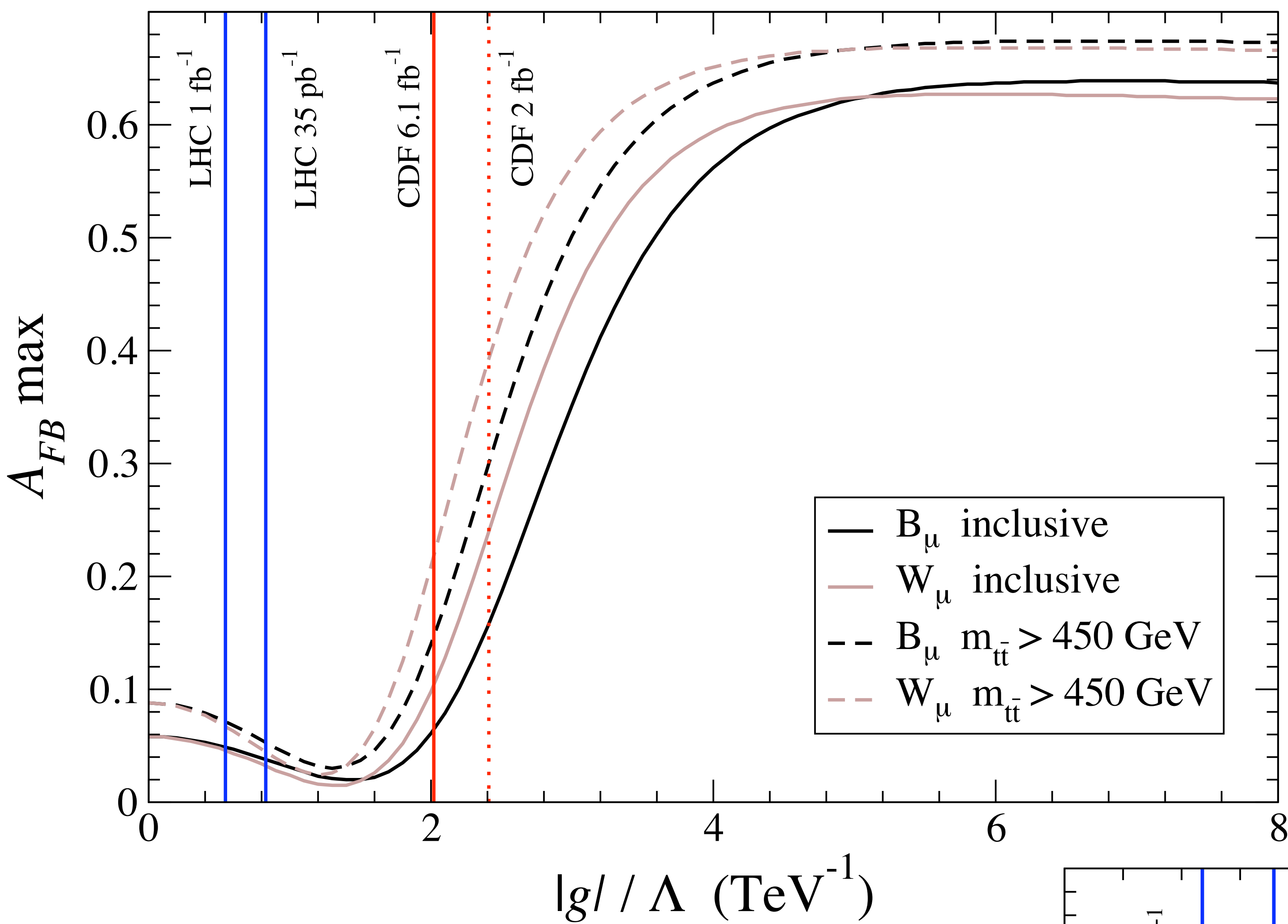
tt vs $t\bar{t}$

- Some common couplings, different combinations in general

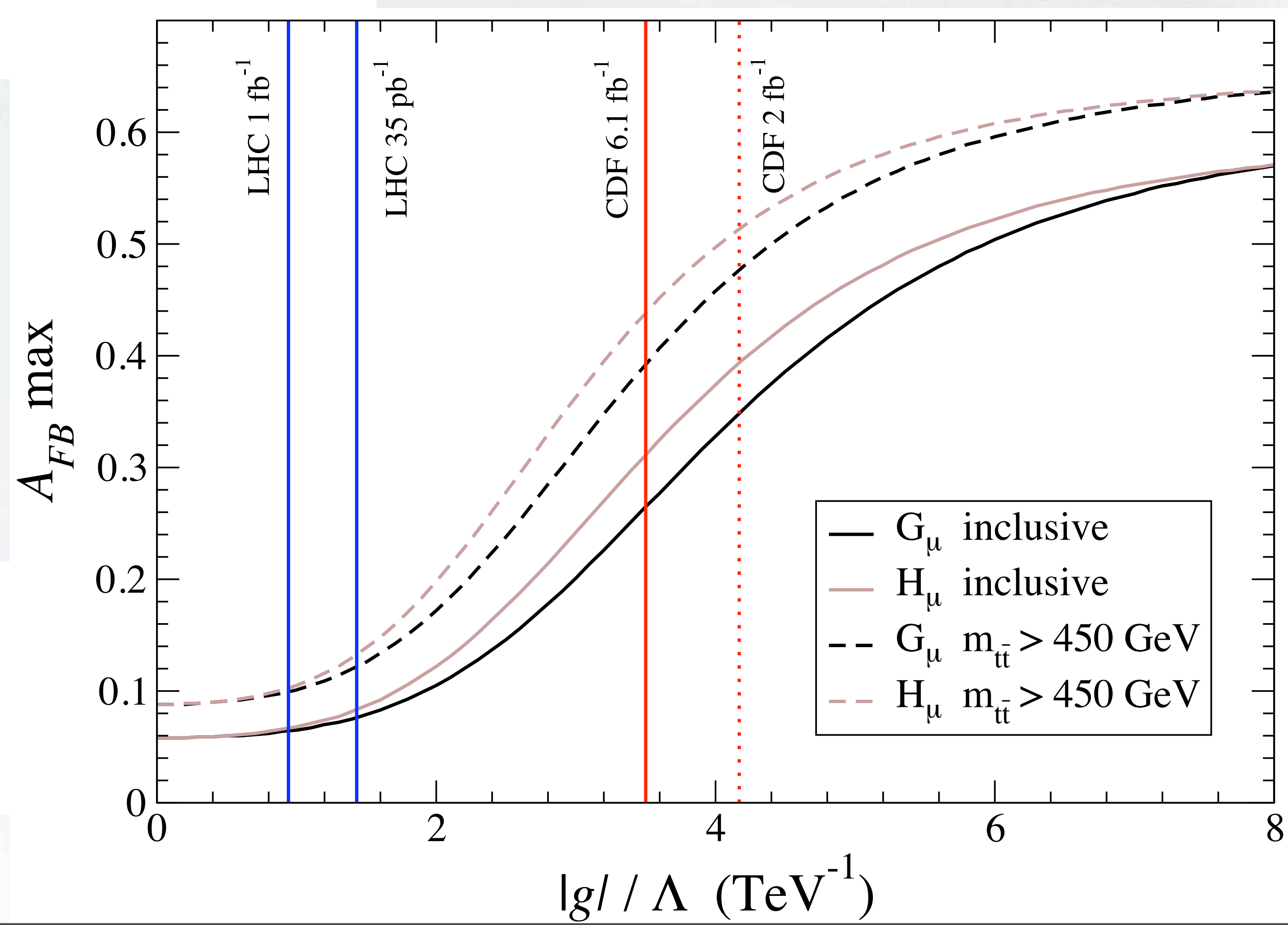
- Direct relation *only* for t-channel exchange of real field with neutral component: $\mathcal{B},\ \mathcal{W},\ \mathcal{G},\ \mathcal{H},$



- No direct relation for t-channel exchange of complex reps: $\phi,\ \Phi$

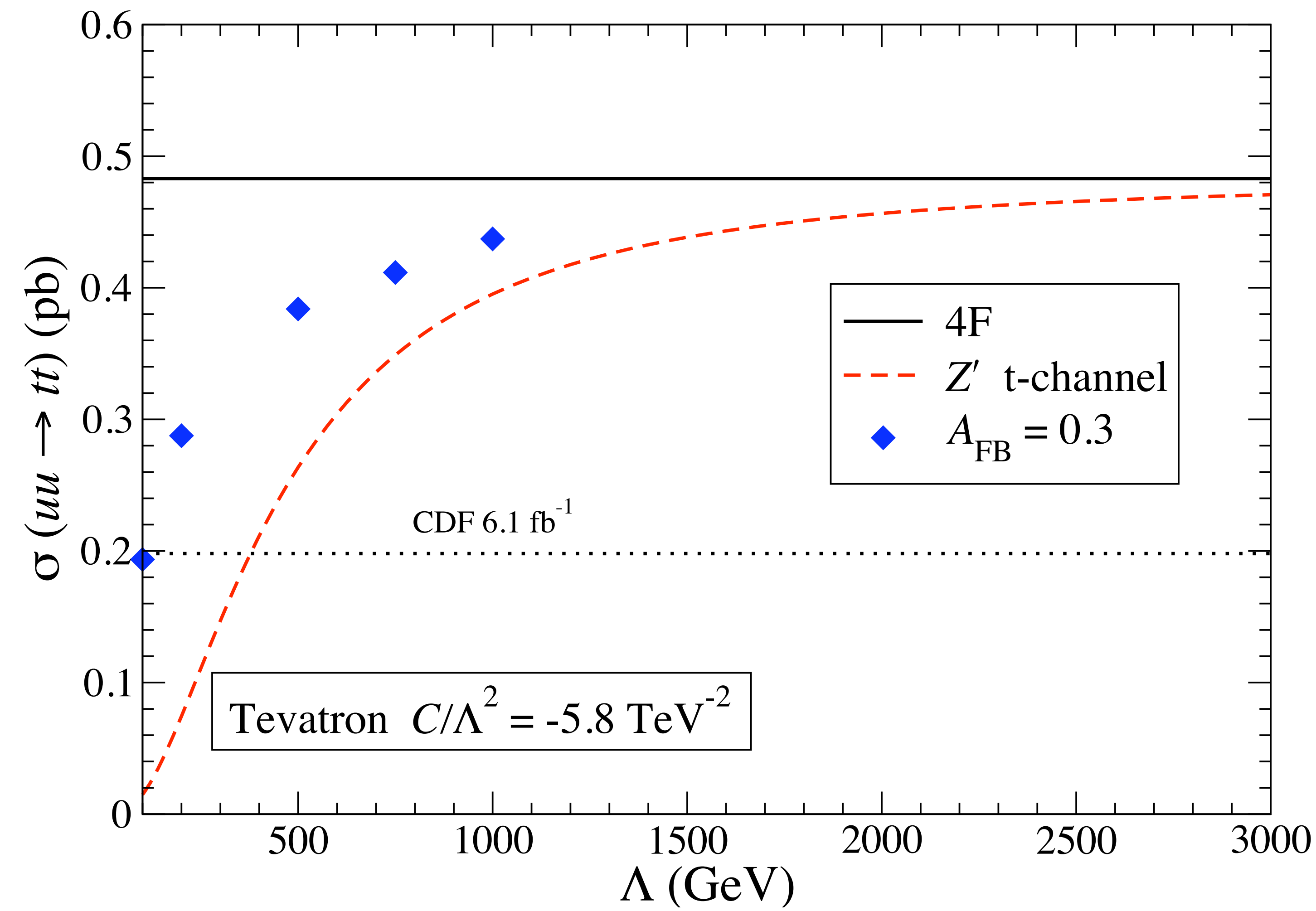


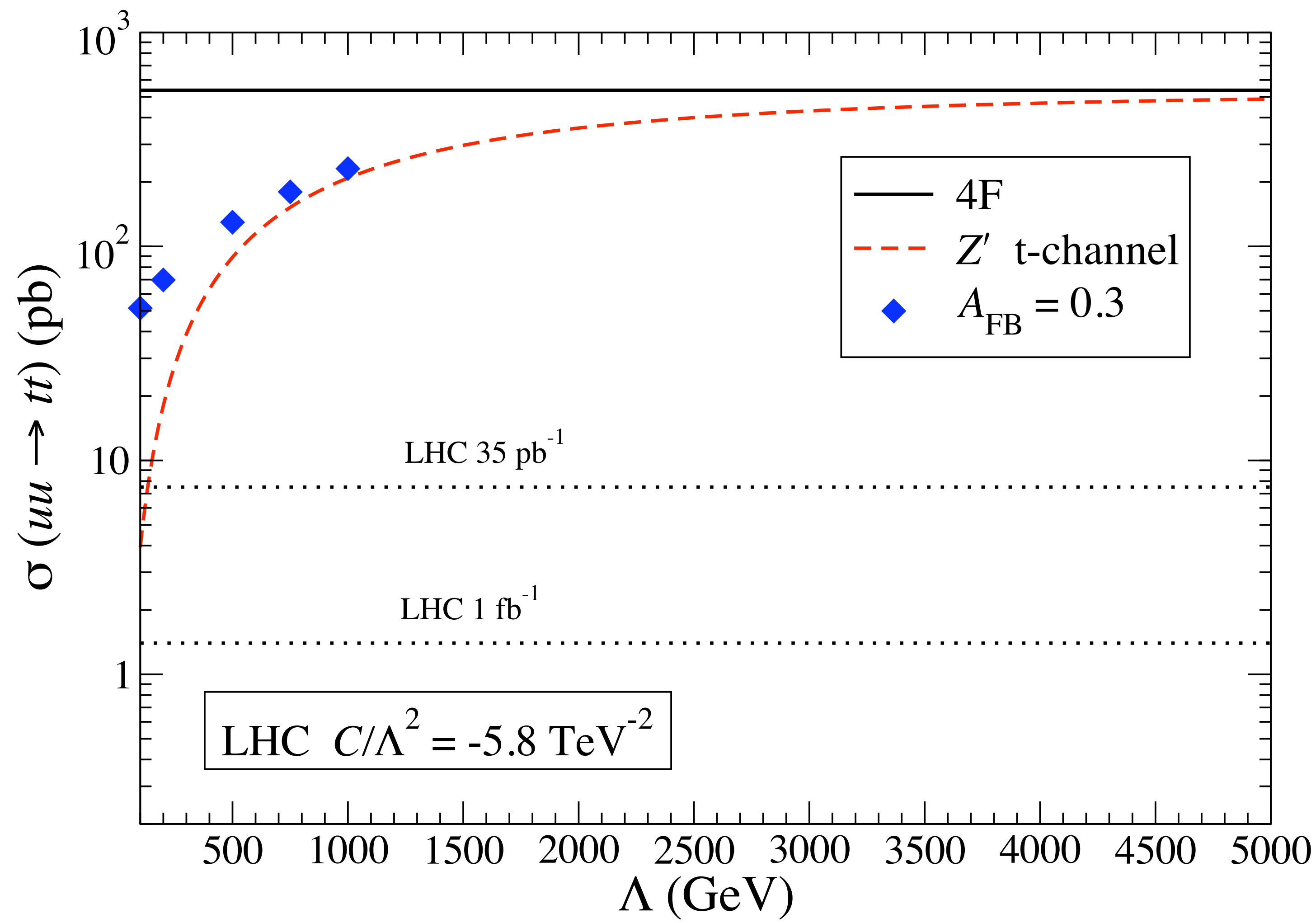
t-channel
heavy Z'



t-channel
heavy Gluon'

t-channel
light Z’



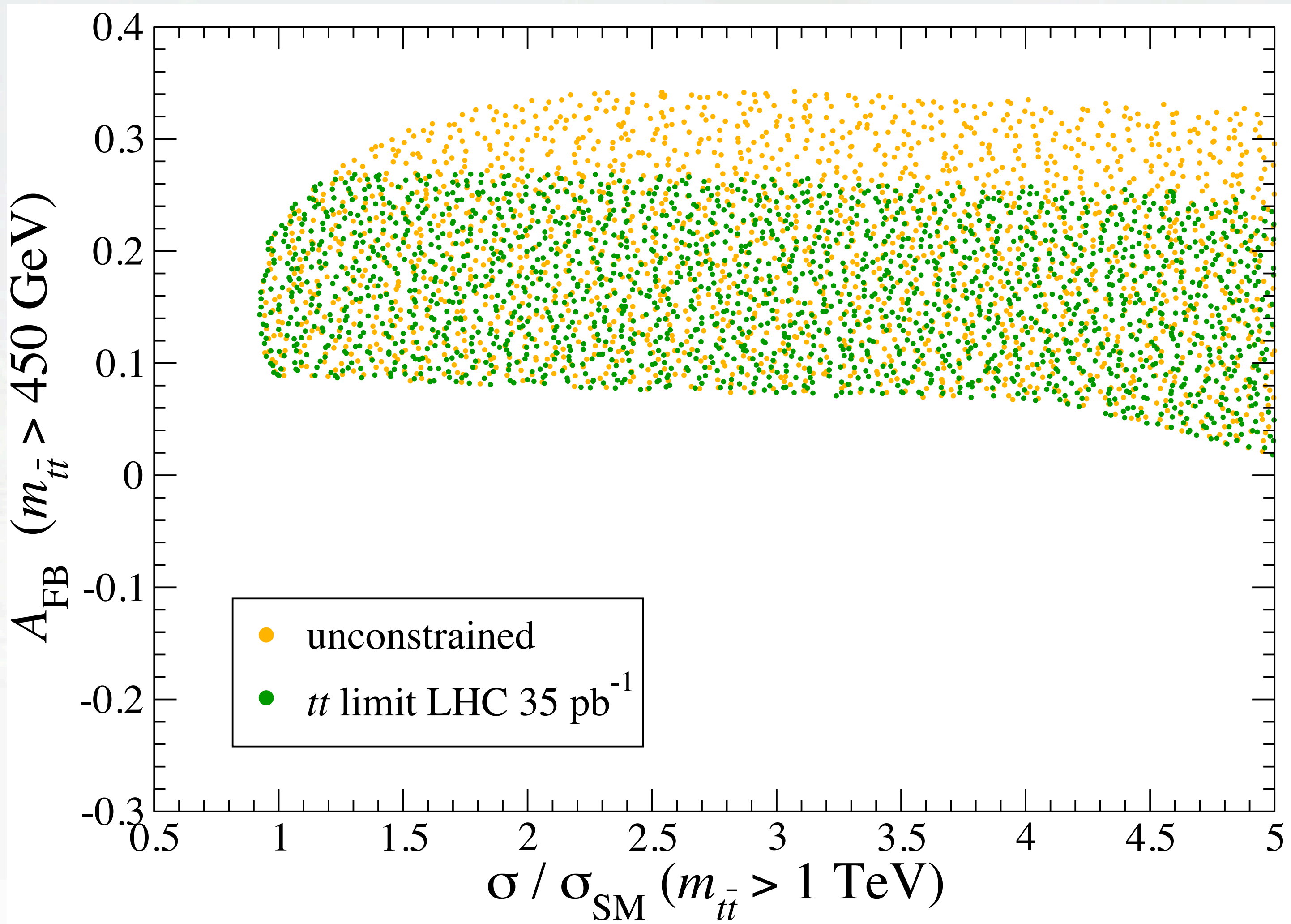


tt vs $t\bar{t}$

Further remarks:

- These strong constraints can be avoided in models with an *additional degenerate boson* with coupling differing by factor of i (to build a complex field).

- Scalar doublets: $|g_{13}^u|^2, \; |g_{31}^u|^2$ vs $|g_{13}^u g_{31}^u|$.



Conclusions

- Intriguing hints of new physics in top pair production at Tevatron

- Also, robust constraints from top pairs at Tevatron and LHC (more results in Aguilar-Saavedra's talk)

- Using gauge symmetries, it is possible to discuss new physics in a general model-independent fashion.

- More (exciting?) news from CERN and Fermilab very soon


Back Slides

(Color , Isospin)$_{\text{Hypercharge}}$ of new fields

Label	Rep.	Interaction Lagrangian	Sym.
$\mathcal{B}_\mu$	$(1,1)_0$	$-\left(g^q_{ij}\bar{q}_{Li}\gamma^\mu q_{Lj} + g^u_{ij}\bar{u}_{Ri}\gamma^\mu u_{Rj} + g^d_{ij}\bar{d}_{Ri}\gamma^\mu d_{Rj}\right)\mathcal{B}_\mu$	$g = g^\dagger$
$\mathcal{W}_\mu$	$(1,3)_0$	$-g_{ij}\bar{q}_{Li}\gamma^\mu\tau^I q_{Lj}\,\mathcal{W}^I_\mu$	$g = g^\dagger$
$\mathcal{B}^1_\mu$	$(1,1)_1$	$-g_{ij}\bar{d}_{Ri}\gamma^\mu u_{Rj}\,\mathcal{B}^{1\dagger}_\mu + \text{h.c.}$	–
$\mathcal{G}_\mu$	$(8,1)_0$	$-\left(g^q_{ij}\bar{q}_{Li}\gamma^\mu\frac{\lambda^a}{2}q_{Lj} + g^u_{ij}\bar{u}_{Ri}\gamma^\mu\frac{\lambda^a}{2}u_{Rj} + g^d_{ij}\bar{d}_{Ri}\gamma^\mu\frac{\lambda^a}{2}d_{Rj}\right)\mathcal{G}^a_\mu$	$g = g^\dagger$
$\mathcal{H}_\mu$	$(8,3)_0$	$-g_{ij}\bar{q}_{Li}\gamma^\mu\tau^I\frac{\lambda^a}{2}q_{Lj}\,\mathcal{H}^{aI}_\mu$	$g = g^\dagger$
$\mathcal{G}^1_\mu$	$(8,1)_1$	$-g_{ij}\bar{d}_{Ri}\gamma^\mu\frac{\lambda^a}{2}u_{Rj}\,\mathcal{G}^{1a\dagger}_\mu + \text{h.c.}$	–
$\mathcal{Q}^1_\mu$	$(3,2)_{\frac{1}{6}}$	$-g_{ij}\varepsilon_{abc}\bar{d}_{Rib}\gamma^\mu\epsilon q^c_{Ljc}\,\mathcal{Q}^{1a\dagger}_\mu + \text{h.c.}$	–
$\mathcal{Q}^5_\mu$	$(3,2)_{-\frac{5}{6}}$	$-g_{ij}\varepsilon_{abc}\bar{u}_{Rib}\gamma^\mu\epsilon q^c_{Ljc}\,\mathcal{Q}^{5a\dagger}_\mu + \text{h.c.}$	–
$\mathcal{Y}^1_\mu$	$(\bar{6},2)_{\frac{1}{6}}$	$-g_{ij}\frac{1}{2}\left[\bar{d}_{Ria}\gamma^\mu\epsilon q^c_{Ljb} + \bar{d}_{Rib}\gamma^\mu\epsilon q^c_{Lja}\right]\mathcal{Y}^{1ab\dagger}_\mu + \text{h.c.}$	–
$\mathcal{Y}^5_\mu$	$(\bar{6},2)_{-\frac{5}{6}}$	$-g_{ij}\frac{1}{2}\left[\bar{u}_{Ria}\gamma^\mu\epsilon q^c_{Ljb} + \bar{u}_{Rib}\gamma^\mu\epsilon q^c_{Lja}\right]\mathcal{Y}^{5ab\dagger}_\mu + \text{h.c.}$	–
ϕ	$(1,2)_{-\frac{1}{2}}$	$-g^u_{ij}\bar{q}_{Li}u_{Rj}\,\phi - g^d_{ij}\bar{q}_{Li}d_{Rj}\,\tilde{\phi} + \text{h.c.}$	–
Φ	$(8,2)_{-\frac{1}{2}}$	$-g^u_{ij}\bar{q}_{Li}\frac{\lambda^a}{2}u_{Rj}\,\Phi^a - g^d_{ij}\bar{q}_{Li}\frac{\lambda^a}{2}d_{Rj}\,\tilde{\Phi}^a + \text{h.c.}$	–
ω^1	$(3,1)_{-\frac{1}{3}}$	$-g_{ij}\varepsilon_{abc}\bar{d}_{Rib}u^c_{Rjc}\,\omega^{1a\dagger} + \text{h.c.}$	–
Ω^1	$(\bar{6},1)_{-\frac{1}{3}}$	$-g_{ij}\frac{1}{2}\left[\bar{d}_{Ria}u^c_{Rjb} + \bar{d}_{Rib}u^c_{Rja}\right]\Omega^{1ab\dagger} + \text{h.c.}$	–
ω^4	$(3,1)_{-\frac{4}{3}}$	$-g_{ij}\varepsilon_{abc}\bar{u}_{Rib}u^c_{Rjc}\,\omega^{4a\dagger} + \text{h.c.}$	$g = -g^T$
Ω^4	$(\bar{6},1)_{-\frac{4}{3}}$	$-g_{ij}\frac{1}{2}\left[\bar{u}_{Ria}u^c_{Rjb} + \bar{u}_{Rib}u^c_{Rja}\right]\Omega^{4ab\dagger} + \text{h.c.}$	$g = g^T$
σ	$(3,3)_{-\frac{1}{3}}$	$-g_{ij}\varepsilon_{abc}\bar{q}_{Lib}\tau^I\epsilon q^c_{Ljc}\,\sigma^{a\dagger} + \text{h.c.}$	$g = -g^T$
Σ	$(\bar{6},3)_{-\frac{1}{3}}$	$-g_{ij}\frac{1}{2}\left[\bar{q}_{Lia}\tau^I\epsilon q^c_{Ljb} + \bar{q}_{Lib}\tau^I\epsilon q^c_{Lja}\right]\Sigma^{Iab\dagger} + \text{h.c.}$	$g = g^T$

Same sign

Kinematics

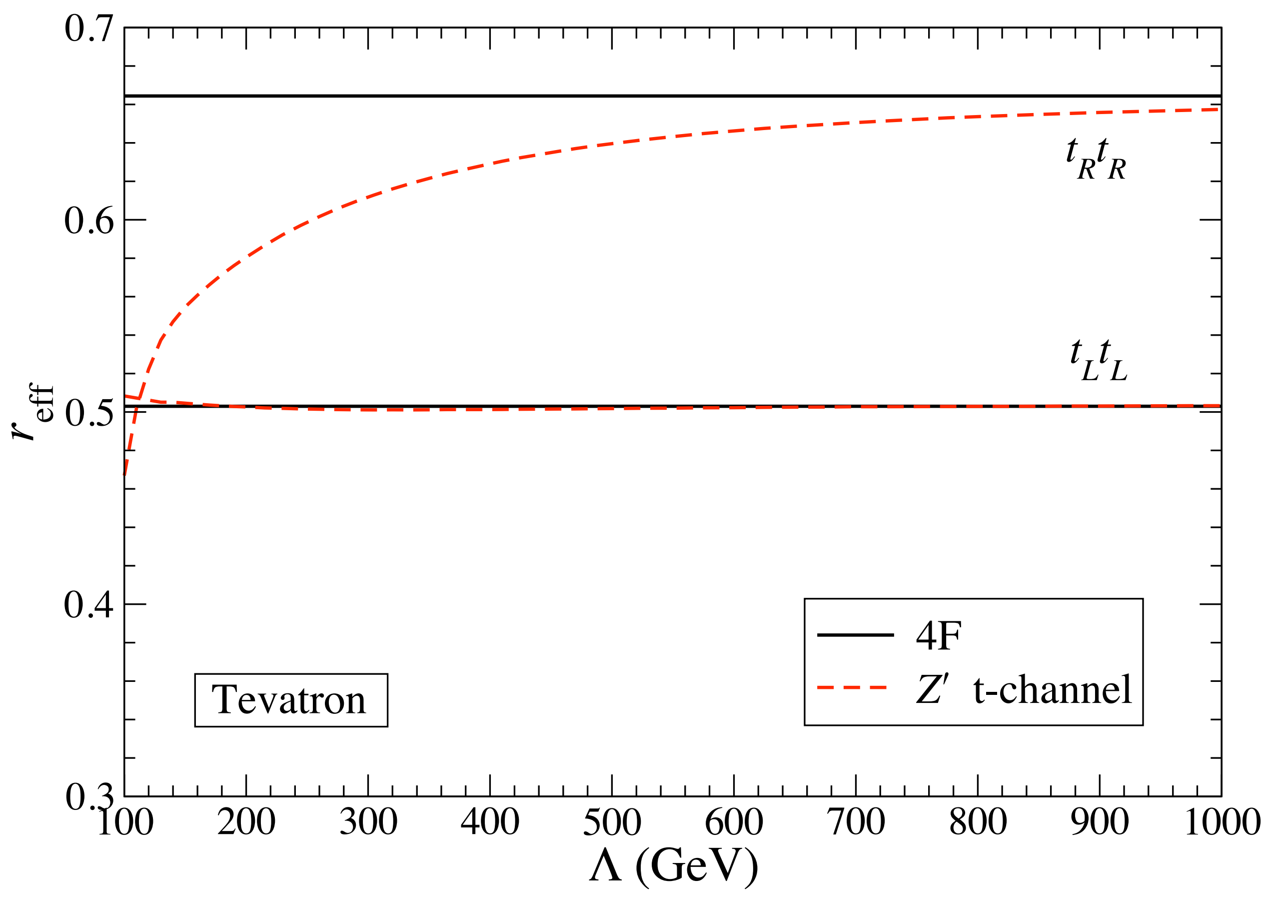
Heavy particles → Effective Operators

Light particles

t → Propagator
Enhances asymmetry

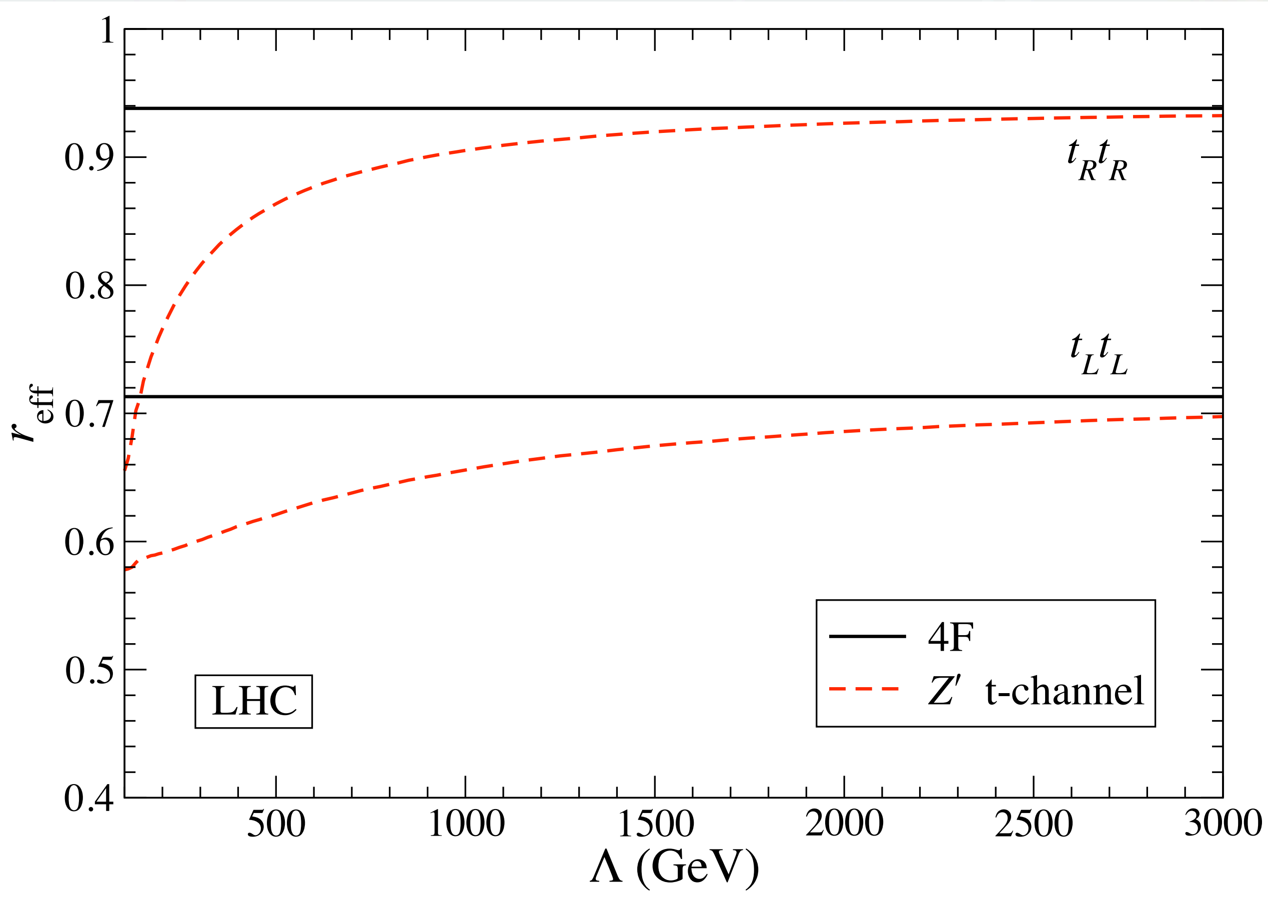
s → Resonance!

u → Propagator
Reduces asymmetry

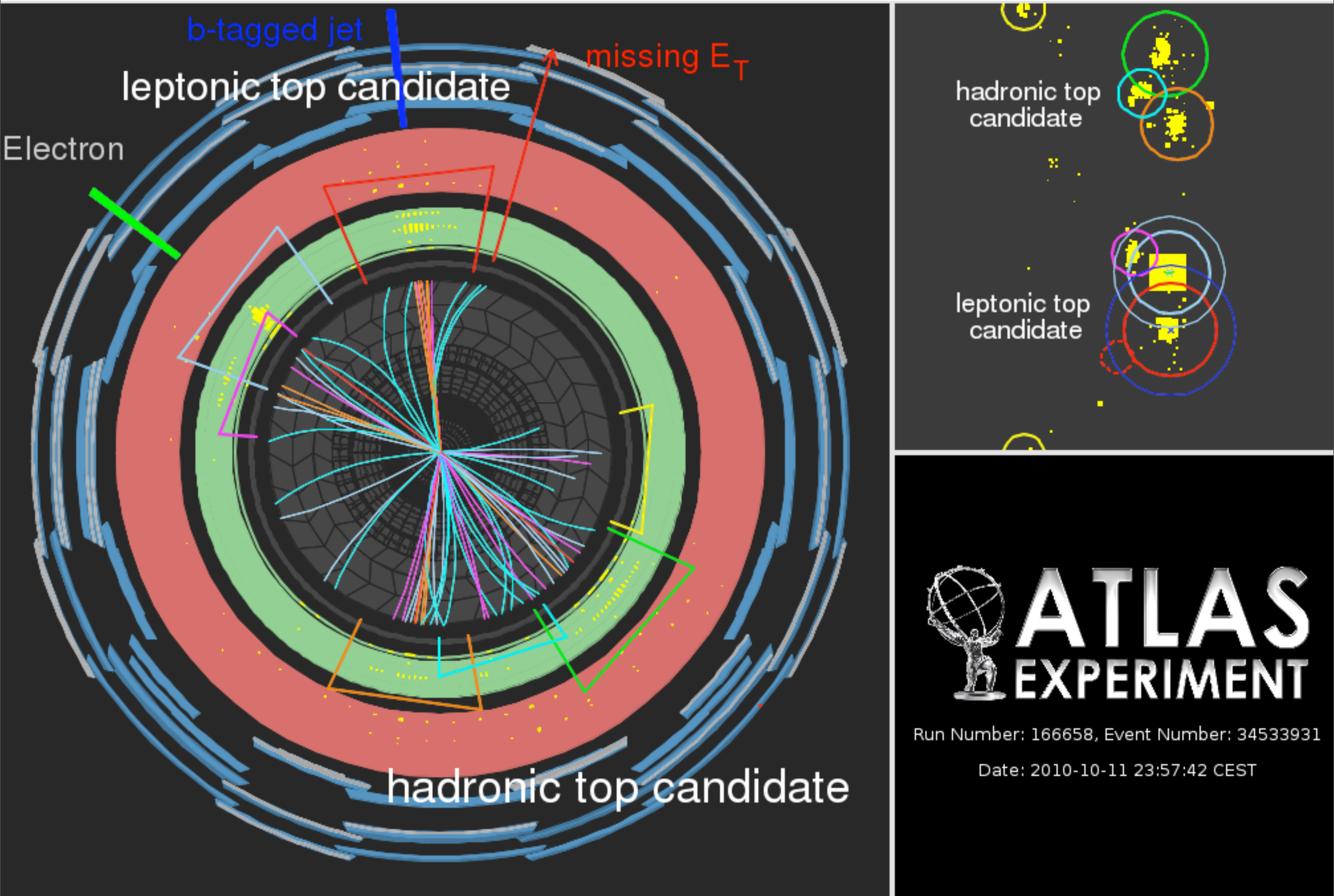


Tevatron

Efficiencies



LHC



b-tagged jet
missing E_T
leptonic top candidate
Electron
hadronic top candidate
hadronic top candidate
leptonic top candidate
ATLAS EXPERIMENT
Run Number: 166658, Event Number: 34533931
Date: 2010-10-11 23:57:42 CEST