Top Forward-backward Asymmetry at the Tevatron

Jing Shu

INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

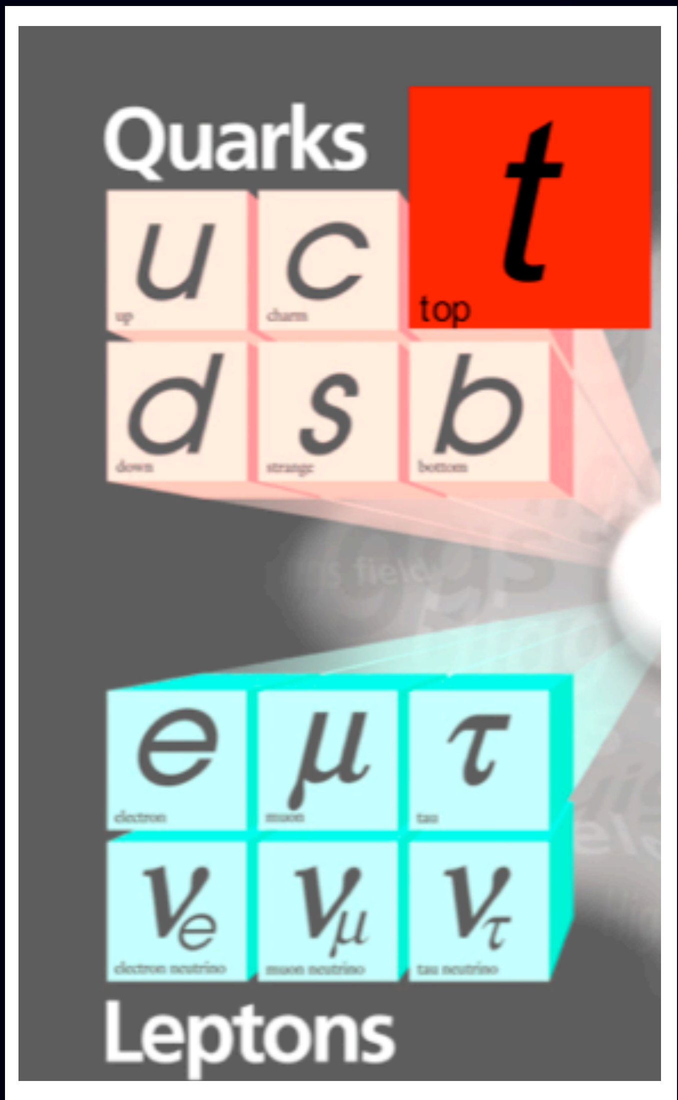
JS, T. Tait, K.Wang, arXiv:0911.XXXX

P. Frampton, JS, K. Wang, arXiv: 0911.XXXX

Outline

- Why top? Why A^t_{FB} ?
- Different explanations
  - s-channel new physics: famaily nonuniversal axigluon
  - t-channel new physics: triplet/sextet scalars
- Conclusion and Outlook

Why top ?



Huge (natural) mass! $(m_t \sim 40\ m_b)$

Great to probe the origin of EWSB and flavor!

- If NP explains the EWSB dynamics, it may strongly couples to the top.
- If NP contributes to flavor violation, it can induce large top flavor violation
- Top compositness

Great window for NP!

Why A_{FB}^{t} ?

History of the measurements:

$$A_{FB}^{t} = 0.20 \pm 0.11_{\text{stat.}} \pm 0.047_{\text{syst.}}$$
$$(0.695 fb^{-1} \text{ CDF T.Schwarz Thesis})$$

$$A_{FB}^{t} = 0.19 \pm 0.09_{\text{stat.}} \pm 0.02_{\text{syst.}}$$
$$(0.9 fb^{-1} \text{ D0 0712.0851})$$

$$A_{FB}^{t} = 0.17 \pm 0.07_{\text{stat.}} \pm 0.04_{\text{syst.}}$$
$$(1.9 fb^{-1} \text{ CDF 0806.2472})$$

$$A_{FB}^{t} = 0.193 \pm 0.065_{\text{stat.}} \pm 0.024_{\text{syst.}} \quad M_t = 175 \text{ GeV}$$
$$(3.2 fb^{-1} \text{ CDF note 9724})$$

The asymmetry measured is persistently large at both CDF and D0

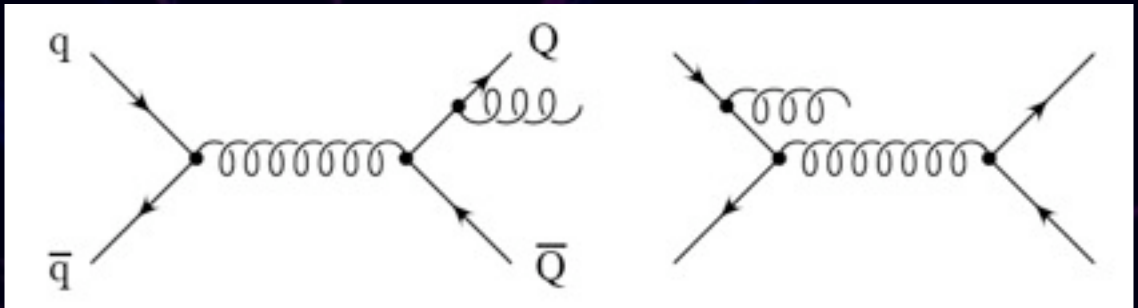
A similar anomaly (A_{FB}^{b} at the Z pole) has been there for a while.

The SM predication

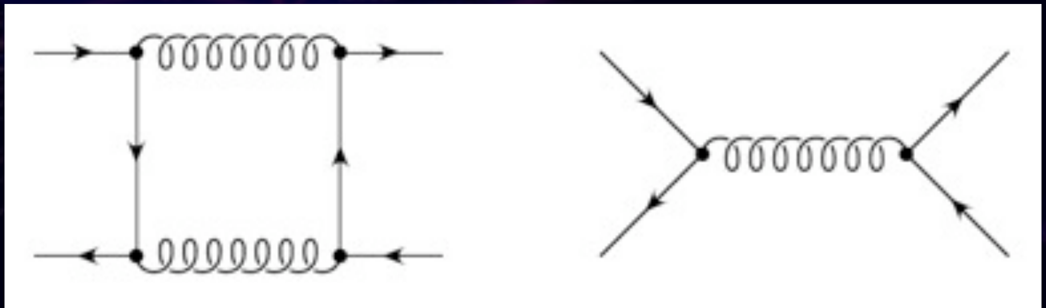
$O(\alpha_S^3)$ QCD interference

$$A_{FB}^{SM} = 0.051 \pm 0.015$$

- ISR w FSR



- Box w Tree diagram



J. Kuhn and G. Rodrigo, PRD 59, 054017 (1999); PRL 81, 49 (1998)

The latest measurement is 2σ away from SM predictions

What else do we know ?

- Total cross section

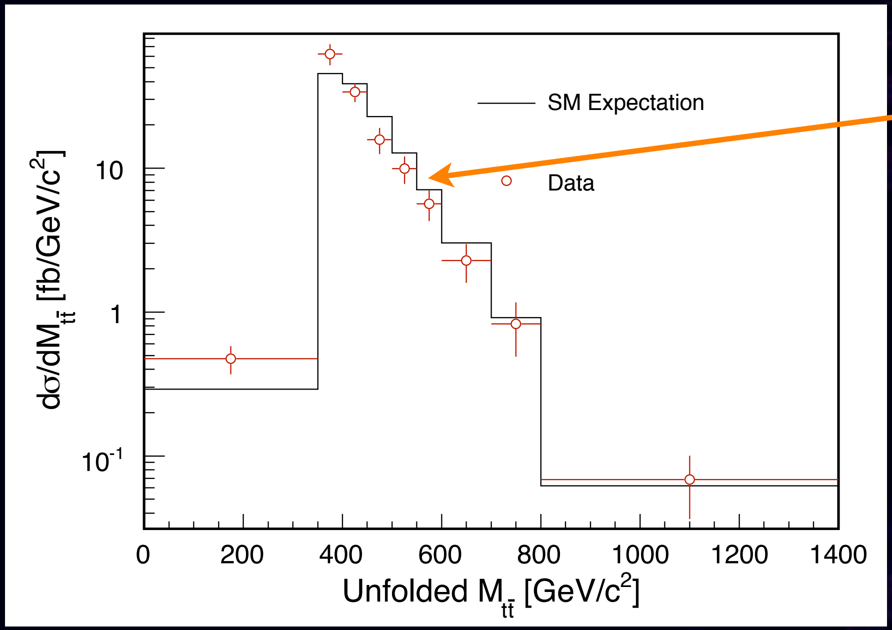
$M_t = 172.5$ GeV

$$\sigma_{t\bar{t}} = 7.50 \pm 0.31_{\rm stat} \pm 0.34_{\rm syst} \pm 0.15_{\rm th}\ {\rm pb}$$
$$\sigma_{t\bar{t}}({\rm theory}) = 7.5^{+0.5}_{-0.7}\ {\rm pb}$$

Consistent with each other

- Differential Cross section

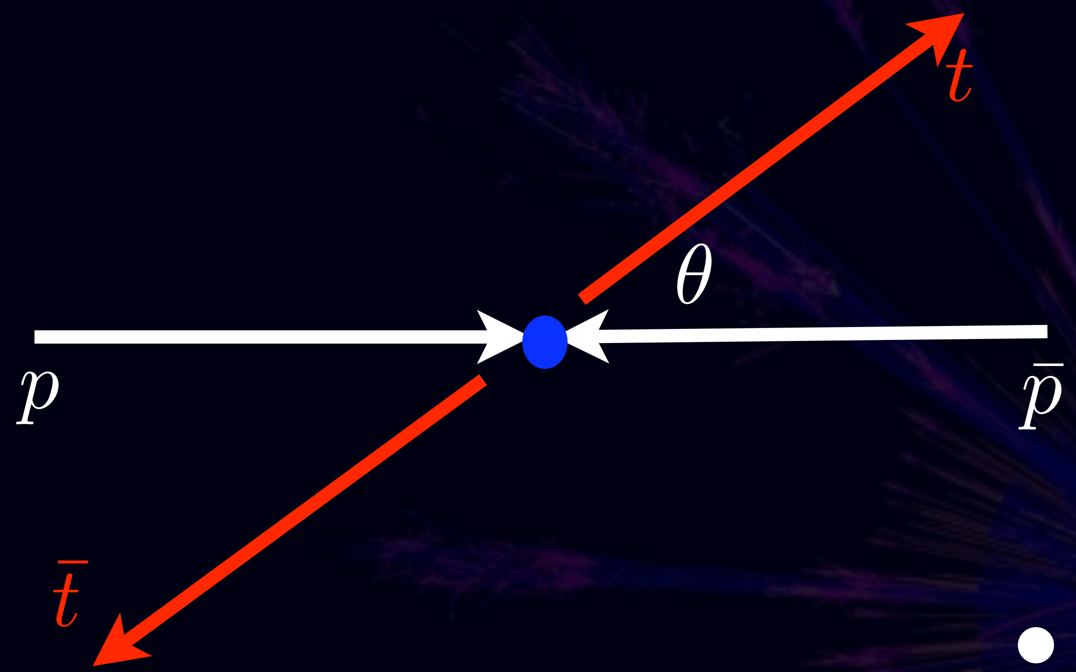
$M_t = 175$ GeV



Data is slightly below the SM prediction for $M_{t\bar{t}} > 400$ GeV

$M_{t\bar{t}}$ [GeV/c^2]	$\mathcal{A}_i$	$d\sigma/dM_{t\bar{t}}$ [fb/GeV/c^2]
≤ 350	0.016±0.001	0.47 ± 0.07 ± 0.08 ± 0.03
350-400	0.023±0.001	62.3 ± 7.0 ± 7.9± 3.7
400-450	0.026±0.001	33.8 ± 4.0 ± 3.0 ± 2.0
450-500	0.027±0.001	15.8 ± 3.0 ± 1.3 ± 0.9
500-550	0.029±0.001	9.9 ± 2.0 ± 0.9 ± 0.6
550-600	0.030±0.001	5.7 ± 1.2 ± 0.7 ± 0.3
600-700	0.030±0.001	2.3 ± 0.6 ± 0.4 ± 0.1
700-800	0.030±0.001	0.8 ± 0.3 ± 0.2 ± 0.1
800-1400	0.023±0.001	0.068 ± 0.032 ± 0.015 ± 0.004
Integrated Cross Section [pb] 6.9 ± 1.0 (stat.+JES)		

Why axi-gluon (s-channel)?



- Parity has to be violated in both the $u\bar{u}$ and $t\bar{t}$ vertex
- The vertex must have both the vector and axi-vector couplings.
- Need axi-vector coupling in the interference. (QCD provides the vector one).

A color octet is preferred for its QCD interference

Axigluon!!!

Wednesday, November 11, 2009

From s-channel new physics

$$\sum |\mathcal{M}|^2 = 1 + c^2 + 4m^2$$
$$+ \frac{2\hat{s}(\hat{s} - m_G^2)}{(\hat{s} - m_G^2)^2 + m_G^2\Gamma_G^2} \left[g_V^q \, g_V^t \, (1 + c^2 + 4m^2) \right.$$
$$\left. + 2 \, g_A^q \, g_A^t \, c \right] + \frac{\hat{s}^2}{(\hat{s} - m_G^2)^2 + m_G^2\Gamma_G^2} \left[((g_V^q)^2 + (g_A^q)^2) \right.$$
$$\times \left((g_V^t)^2 (1 + c^2 + 4m^2) + (g_A^t)^2 (1 + c^2 - 4m^2) \right)$$
$$\left. + 8 \, g_V^q \, g_A^q \, g_V^t \, g_A^t \, c \right] \quad , \qquad (3)$$

$$m = m_t/\sqrt{s}$$

$$c = \beta \cos\theta$$

Provide the asymmetry from interference (Only axivector coupling is needed)

$g_A^q g_A^t < 0$

For the new physics square term, need bot the vector and axi-vector coupling from the new resonance (like b asymmetry at LEP from Z)

$g_V^q g_A^q g_V^t g_A^t > 0$

The model

Conventional chiral color model (family universal)

$g_A^q = g_A^t$ Wrong sign!

A family nonuniversal model (split 1st, 2nd with 3rd, 4th generation)

Cancel the anomaly
Not necessary in ED

Field	Q_i	u_i^c	d_i^c	Q_j	u_j^c	d_j^c	Σ	H_q	L_k	e_k^c	H_l
$SU(3)_A$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\bar{\mathbf{3}}$	$\bar{\mathbf{3}}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$SU(3)_B$	$\mathbf{1}$	$\bar{\mathbf{3}}$	$\bar{\mathbf{3}}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\bar{\mathbf{3}}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$SU(2)_L$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{2}$
$U(1)_Y$	$+1/3$	$-4/3$	$+2/3$	$+1/3$	$-4/3$	$+2/3$	0	$+1$	-1	$+2$	$+1$

$i = 1, 2 \quad j = 3, 4$

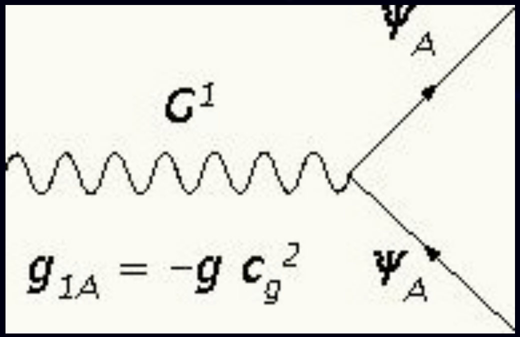
The model

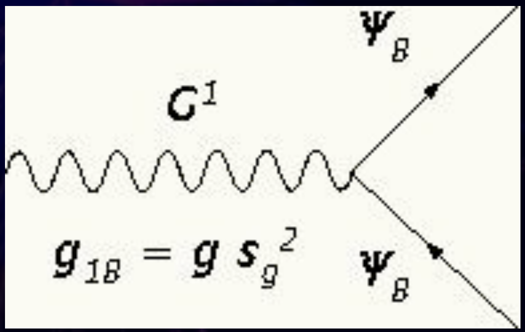
The scalar $\Sigma\ (3,\bar{3})$ breaks $SU(3)_A \times SU(3)_B$ into the diagnol one $SU(3)_C$

$$\begin{pmatrix} G_\mu^1 \\ G_\mu^0 \end{pmatrix} = \begin{pmatrix} s_g & -c_g \\ c_g & s_g \end{pmatrix} \begin{pmatrix} A_\mu \\ B_\mu \end{pmatrix}$$

$$\theta = \mathrm{Arctan}(g_A/g_B)$$

$$g_s = \frac{g_A g_B}{\sqrt{g_A^2 + g_B^2}} \qquad g = \sqrt{g_A^2 + g_B^2}$$



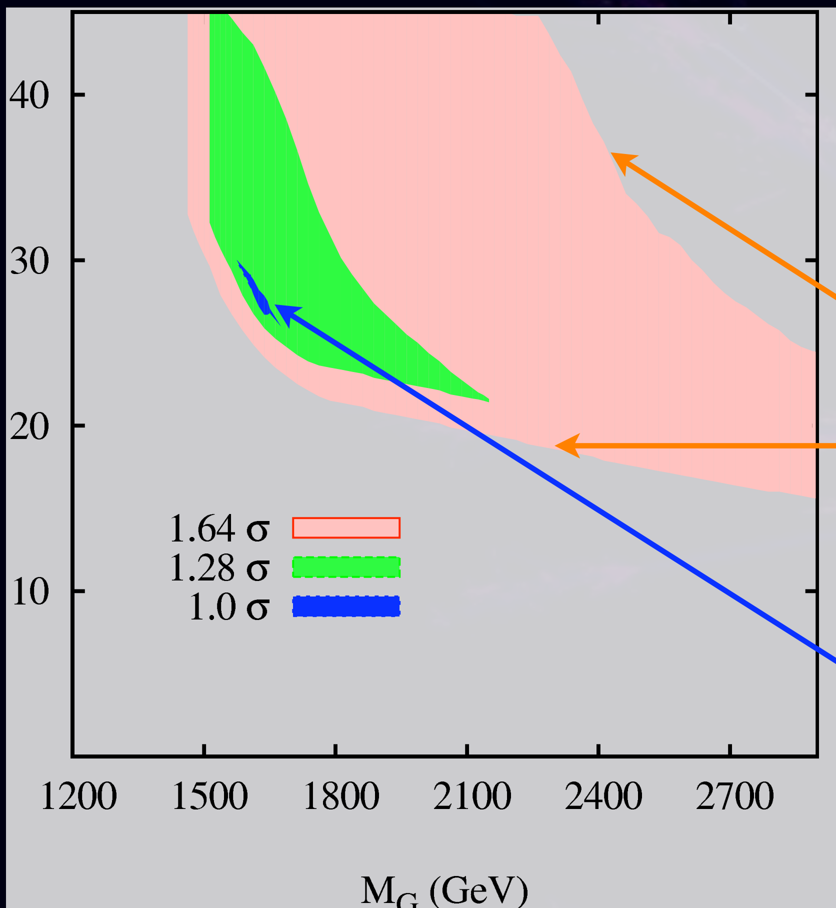


$$g_v^q = g_v^t = -g c_{2g} \qquad -g_a^q = g_a^t = g \qquad c_{2g} \equiv \cos(2\theta)$$

450-500	0.027±0.001	15.8 ± 3.0 ± 1.3 ± 0.9
500-550	0.029±0.001	9.9 ± 2.0 ± 0.9 ± 0.6
550-600	0.030±0.001	5.7 ± 1.2 ± 0.7 ± 0.3
600-700	0.030±0.001	2.3 ± 0.6 ± 0.4 ± 0.1
700-800	0.030±0.001	0.8 ± 0.3 ± 0.2 ± 0.1
800-1400	0.023±0.001	0.068 ± 0.032 ± 0.015 ± 0.004
Integrated Cross Section [pb] 6.9 ± 1.0 (stat.+JES)		

Nicely fit the data!

The $M_{t\bar{t}}$ constrain are from the last bin assuming the K factor there is 1



θ

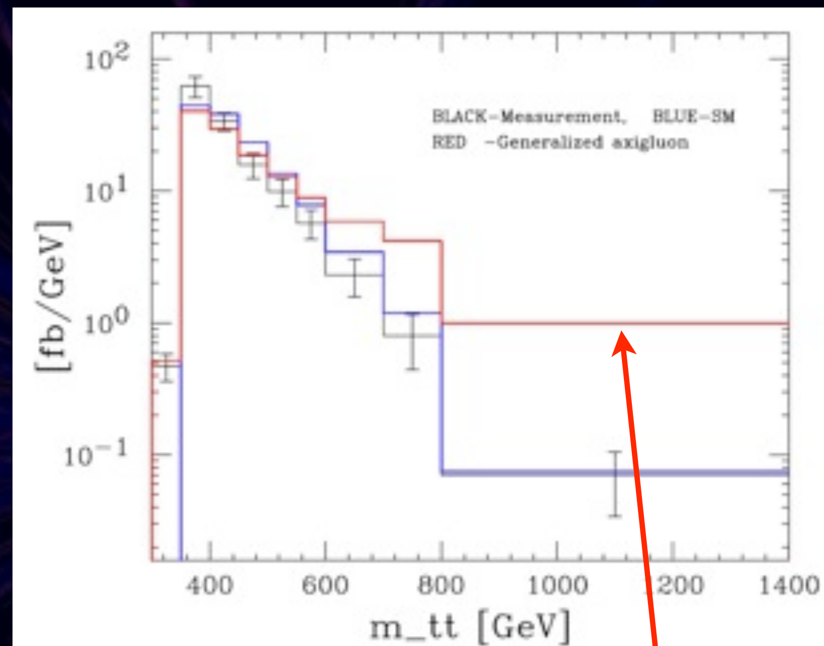
Large parameter space for 90%CL (1.68 σ)

Allowed region for one sigma

Other models.......

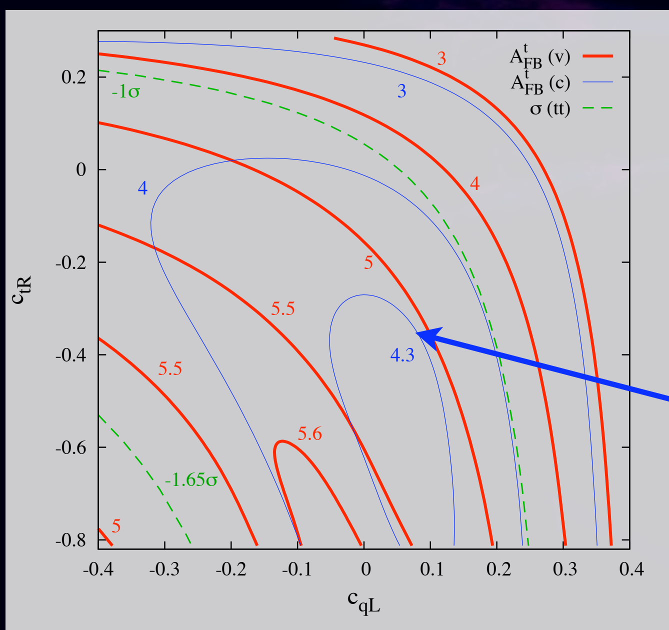
Conventinal axigluon

Too light to explain the asymmery (1.2TeV)



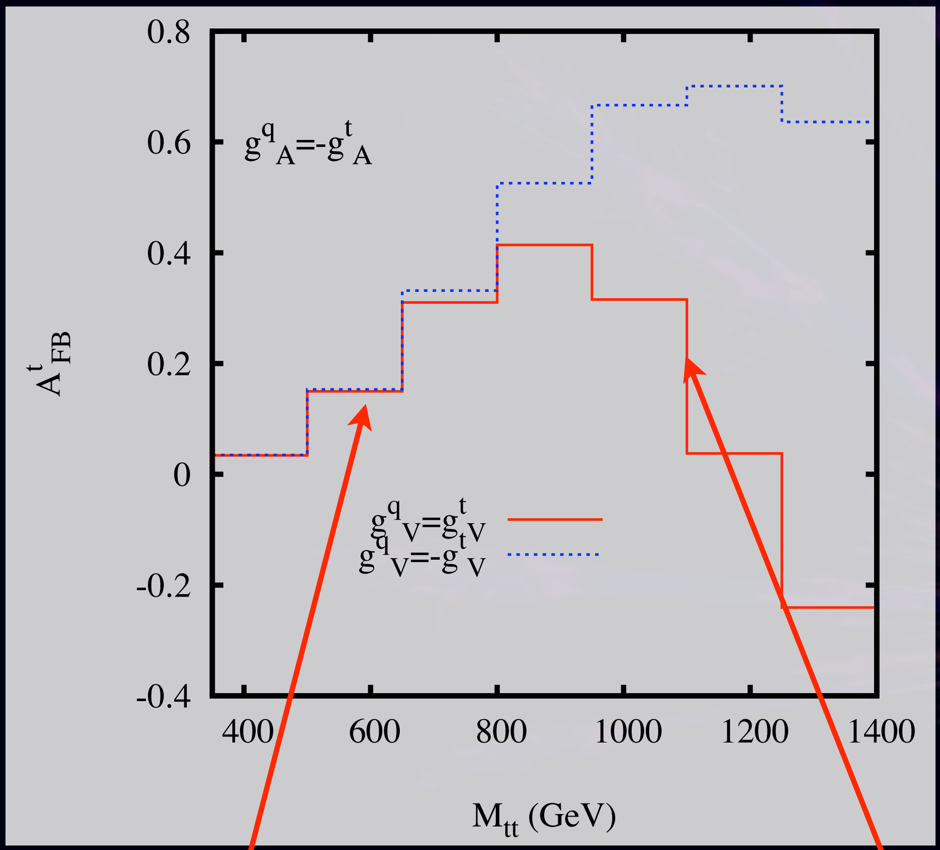
Contaminate the invaraint mass distribution

RS KK gluon

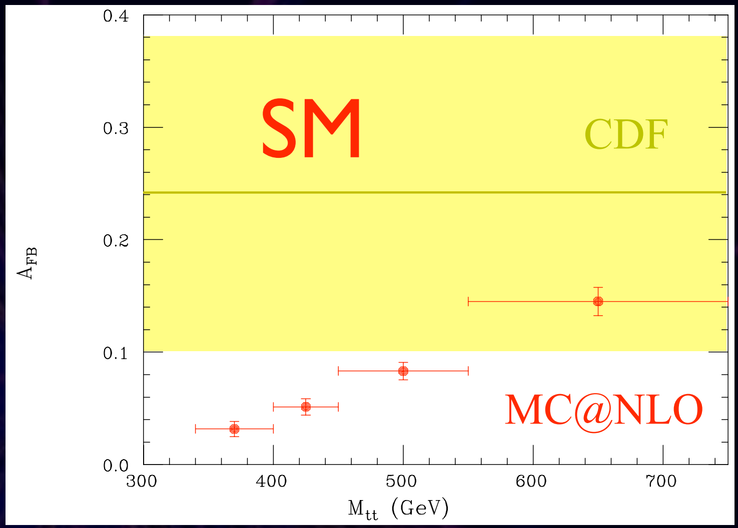


Maximal 4.3%

Predictions without resonance



Can be checked in the near future!!!!

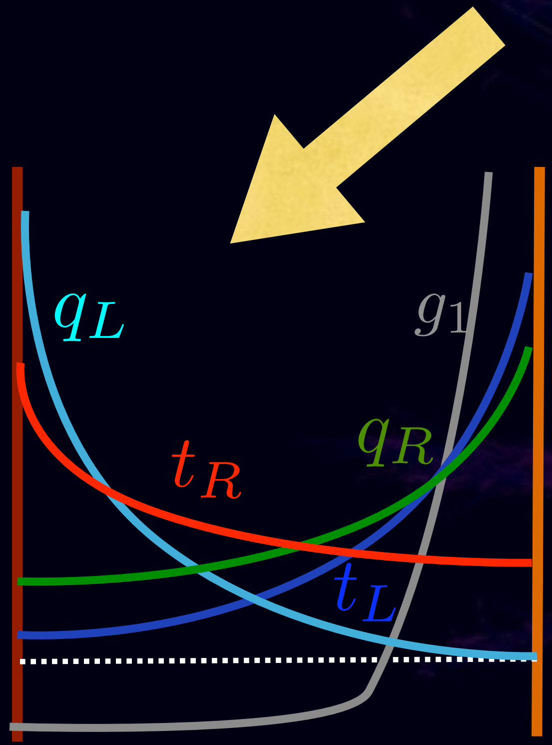


The SM model contribution reduces....

The new physics square term dominate (negative asymmetry) when approaching the resonance

New organizing principle?

Cartoon picture for the (inverse?) deconstructed version.



- Left-handed and right-handed fermions are localized at each brane.

$$g_L^q g_R^q < 0 \qquad g_L^t g_R^t < 0$$
$$g_A^q > g_V^q \qquad g_A^t > g_V^t$$

- Light quarks and top quarks with the same chirality are localized at each brane.

$$g_A^q g_A^t < 0 \qquad g_V^q g_V^t > 0$$

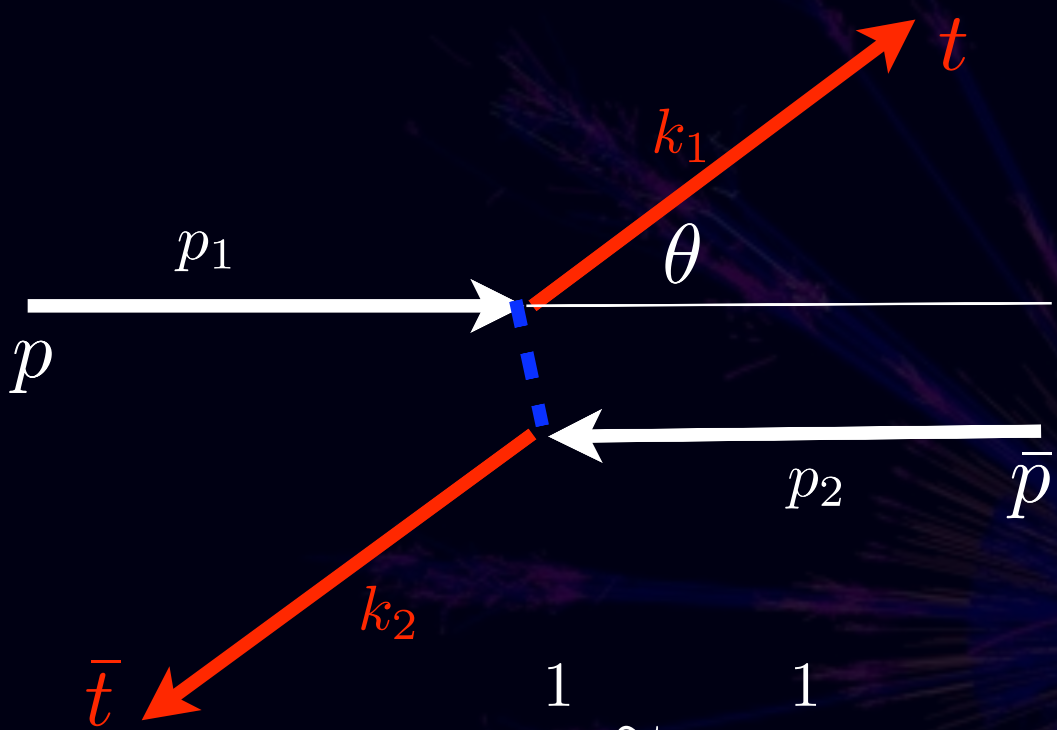
What is the EWP constrain in RS?

How about flat ED?

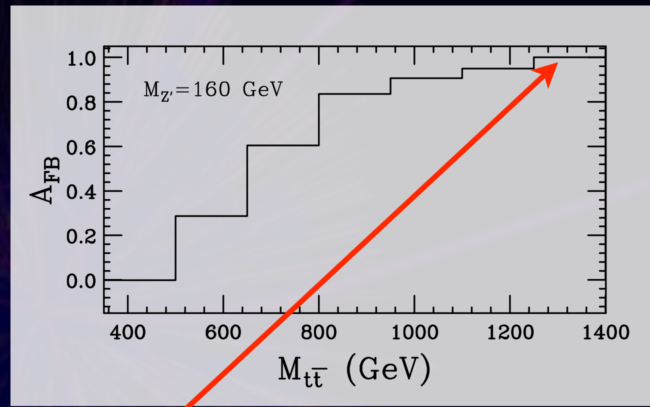
See Seongchan Park's talk

The t-channel explanation

S. Jung, H.Murayama, A.Pierce, J.Wess 0907.4112
K. Cheung, W. Keung, T.Yuan 0908.2589
JS, T.Tait, K.Wang, 0911.XXXX



$$\frac{1}{t_\phi} \sim \frac{1}{1 - \cos\theta}$$



Massless: collinear sigularity

A full analysis shows for scalars it is somewhat different.......

T-channel explanation (scalar)

JS, T. Tait, K. Wang, 0911.XXXX

$$\mathcal{L}_\phi = D_\mu \phi^\dagger D^\mu \phi - M_\phi^2 |\phi|^2 + \phi^a \bar{\hat{t}} T_r^a (y_S + y_P \gamma_5) u + h.c.,$$

$$3 \times \bar{3} = 8 + 1$$
$$3 \times 3 = 6 + \bar{3}$$

$$\hat{t} = \begin{cases} t & \text{(octet or singlet)} \\ t^c & \text{(triplet or sextet)} \end{cases}$$

$$t^c = i\gamma^0\gamma^2 \bar{t}$$

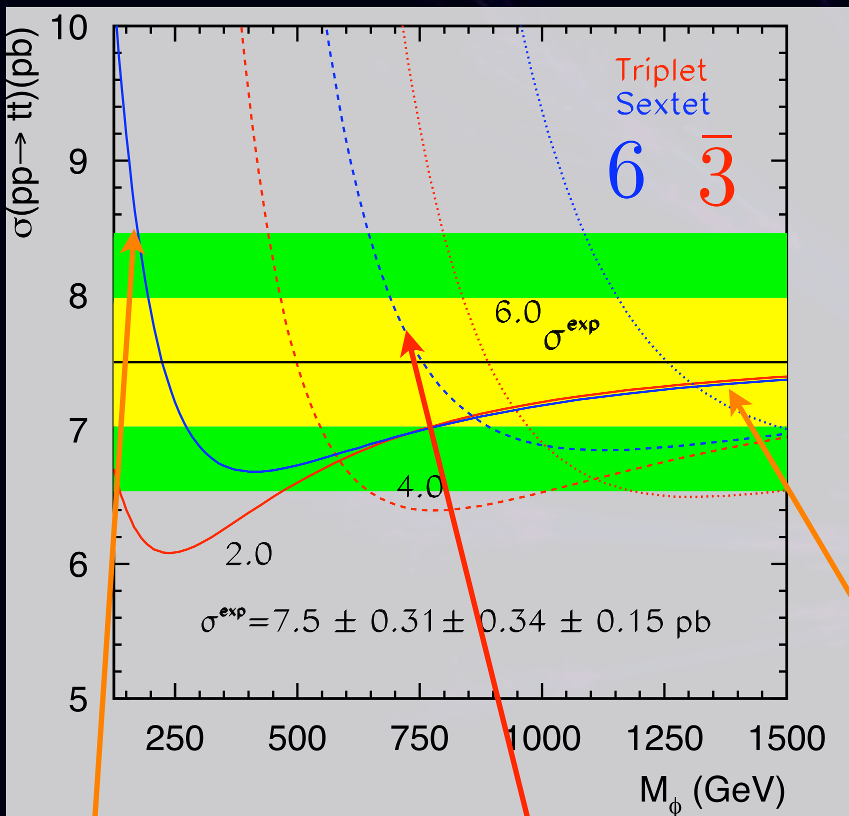
Color Factor	Octet	Singlet	Sextet	Triplet
$C_{(0)}$	$-2/3$	4	1	1
$C_{(1)}$	4	3	3	-3/2
$C_{(2)}$	2	9	3/2	3/4

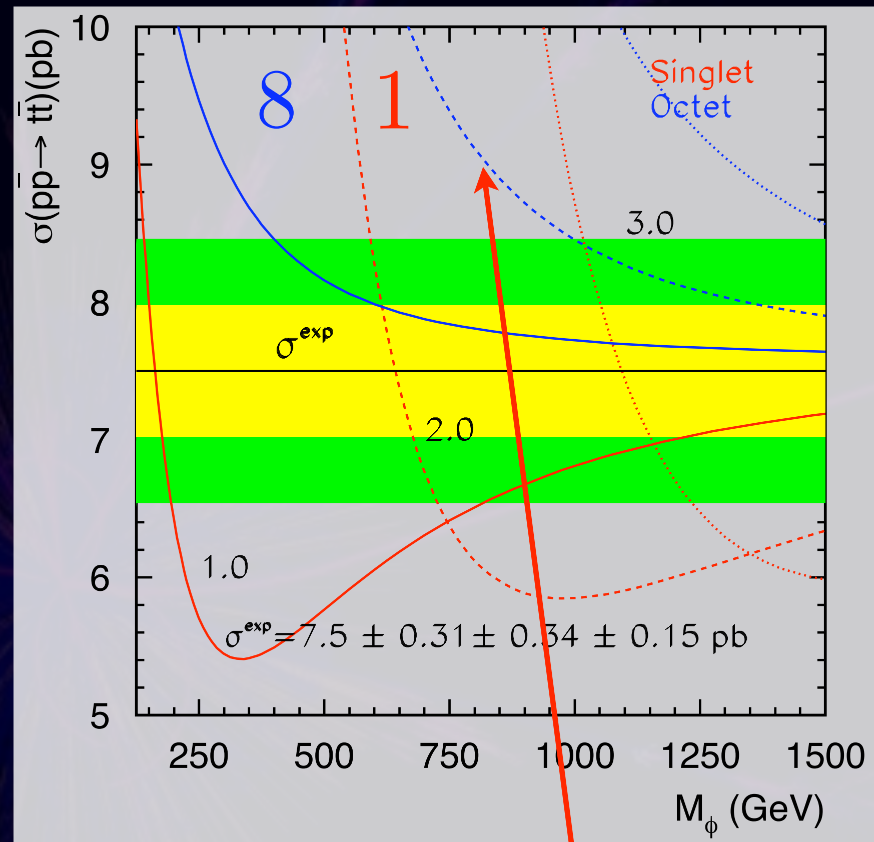
$$\sum |\mathcal{M}|^2 = 8 g_S^4 (1 + c_\theta^2 + 4m^2) + 2y^2 g_S^2 C_{(0)} s \frac{(1-c_\theta)^2 + 4m^2}{t_\phi} + y^4 C_{(2)} \frac{s^2 (1-c_\theta)^2}{t_\phi^2} .$$

$$t_\phi = (p_1 - k_1)^2 - m_\phi^2$$

Taylor Expansion: $\frac{1}{t_\phi} \sim 1 + \alpha c_\theta$

The total cross section





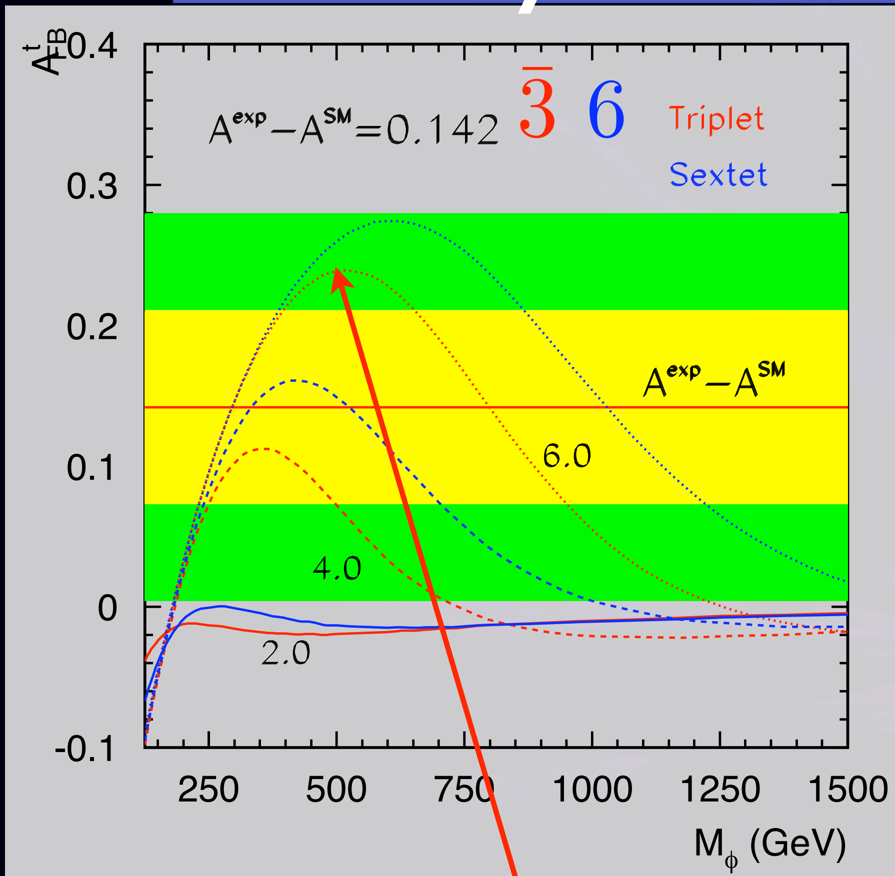
New Physics square term dominate!

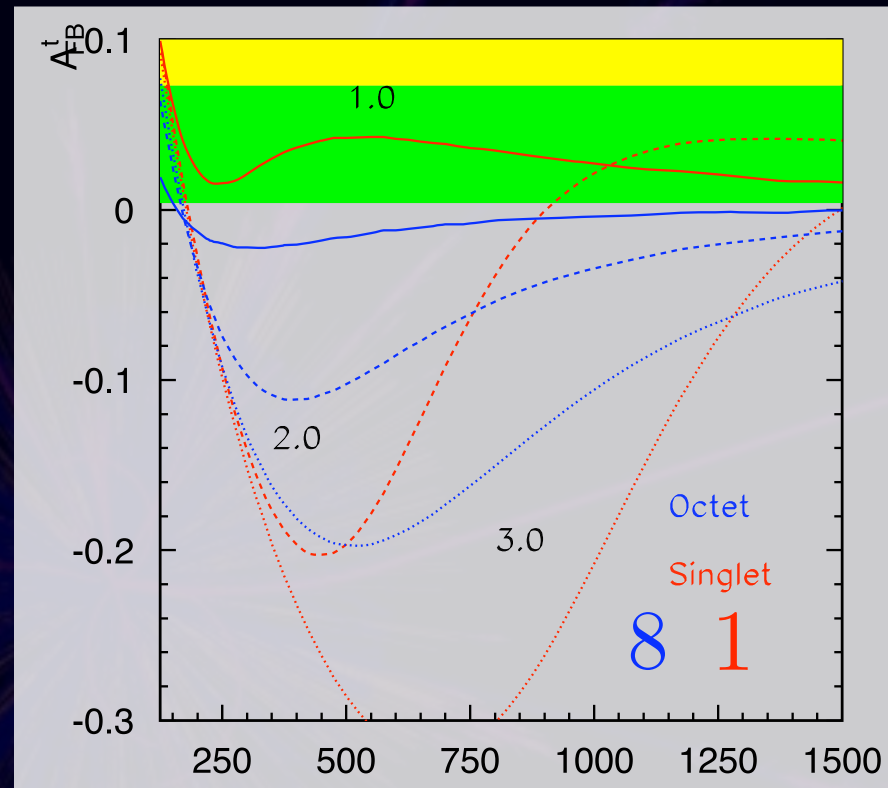
Competition makes no deviation

Interference term dominate!

No competition for octet.

The asymmetry





Intermediate mass region allows large positive asymmetrty.

Details of the Explanations......

$$\sum |\mathcal{M}|^2 = 8g_S^4(1 + c_\theta^2 + 4m^2) +$$
$$2y^2 g_S^2 C_{(0)} s \frac{(1 - c_\theta)^2 + 4m^2}{t_\phi} + y^4 C_{(2)} \frac{s^2(1 - c_\theta)^2}{t_\phi^2}.$$

The two cancel each other (competition)

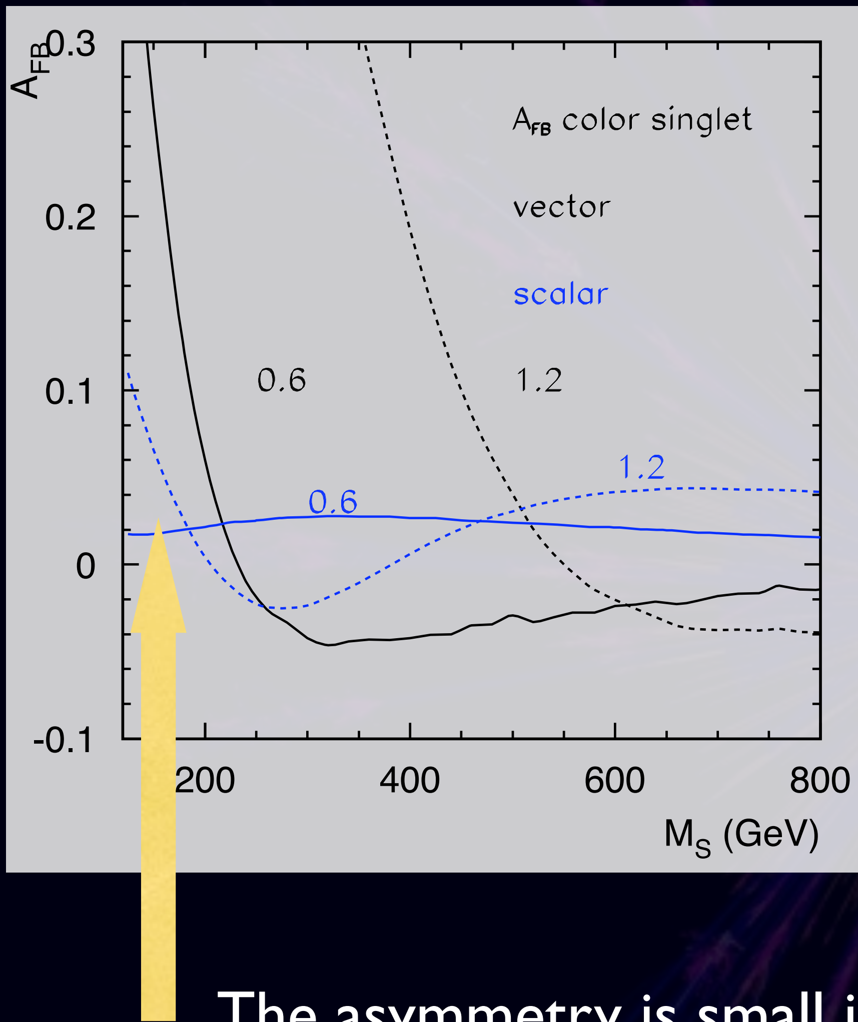
Dominate at the low mass region.

Dominate at the Intermediate mass region.

Dominate at the Intemediate mass region.

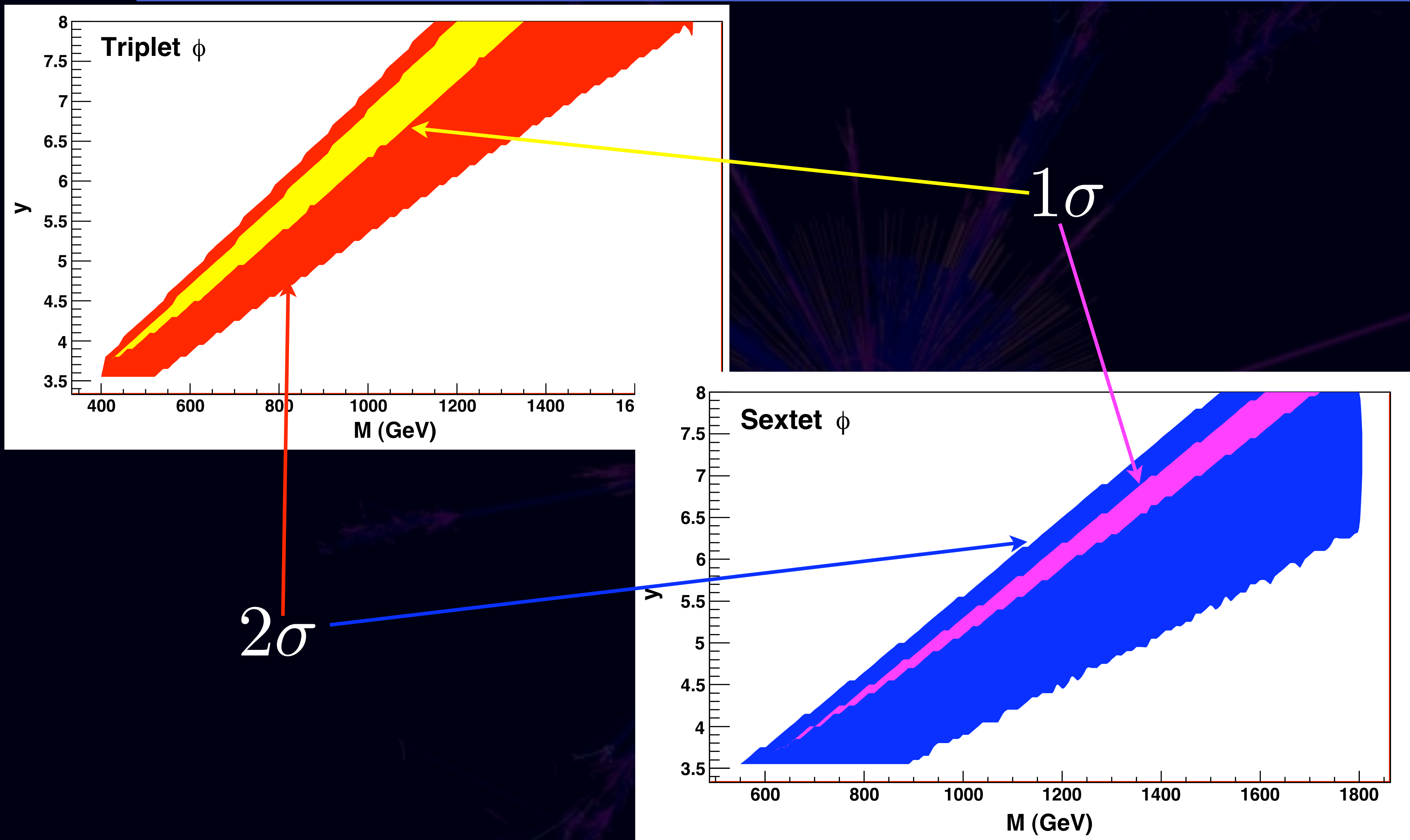
Taylor Expansion: $\frac{1}{t_\phi} \sim 1 + \alpha c_\theta$

Scalar vs vector bosons

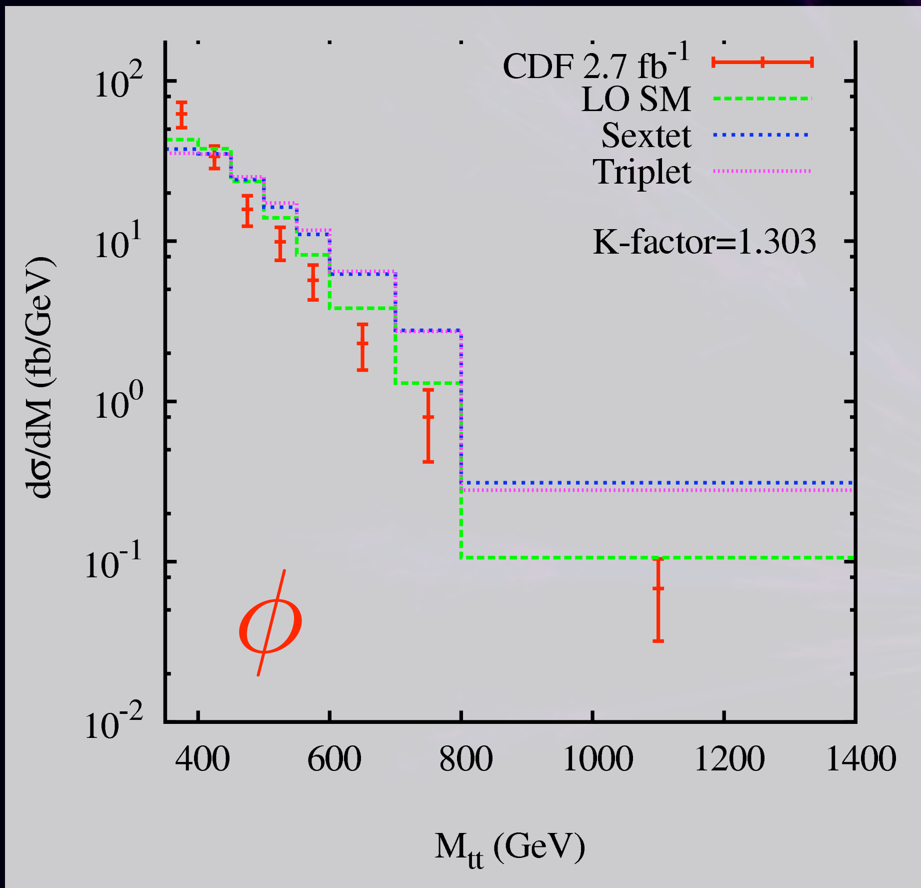


The asymmetry is small in the scalar case for low masses.

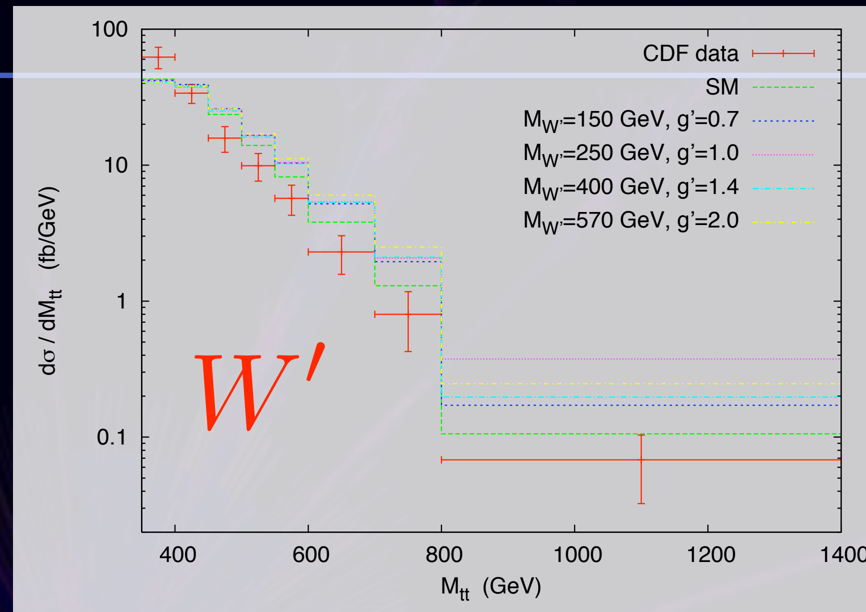
Parameter scan (scalar)



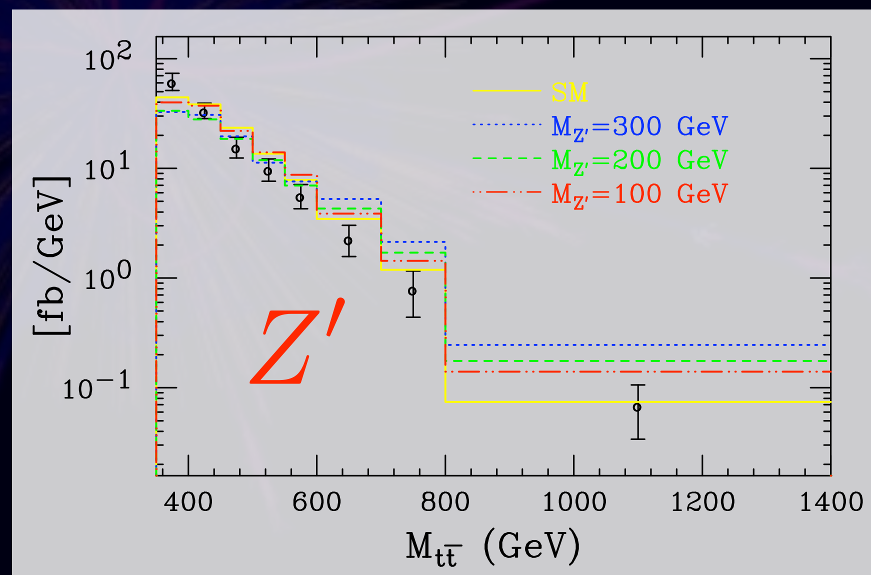
Invaraint mass distributions



JS, T. Tait, K. Wang, 0911.XXXX



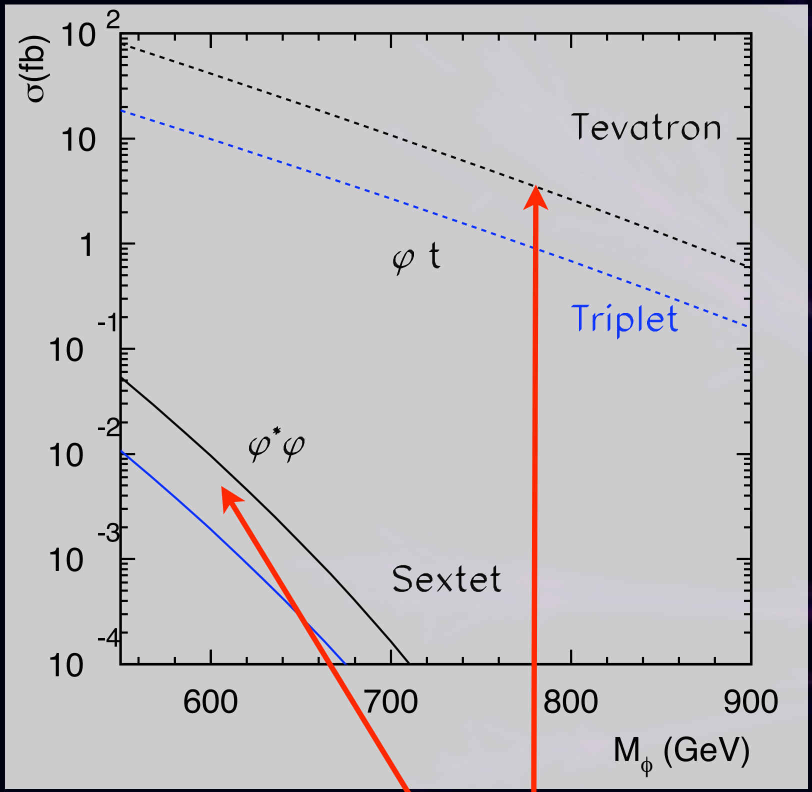
K. Cheung, W. Keung, T. Yuan 0908.2589

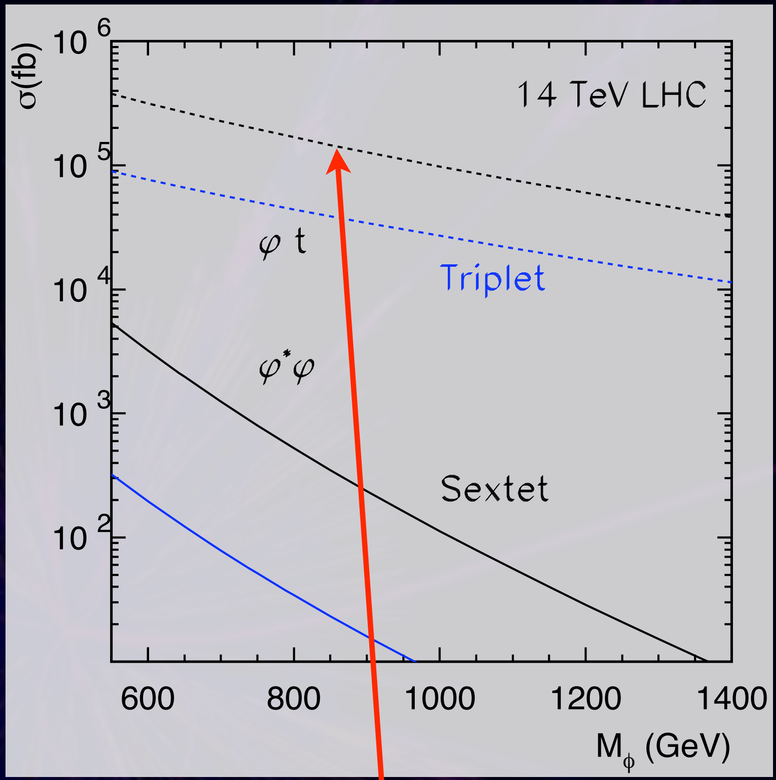


S. Jung, H. Murayama, A. Pierce, J. Wess 0907.4112

Difficult for all......

Tevatron / LHC signals





Too small to contaminate the Tevatron ttbar events

10% ~ 1 of the LHC ttbar events (large E and gluon pdf)

Prediction: ttbar always assicated with an extra hard jet!

Conclusion

Great!

- New axigluon works very well....... (with new Tevatron predictions to distinguish it)
- T-channel sextet/triplet works OK. (with LHC predictions)
- S-channel models typically are difficult to get very large asymmetry.
- T-channel models typically are difficult in the ttbar invariant mass distribution.

Outlook

- Models explain the EWSB and asymmetry.
- A effective theory approach including the gluon ttbar vertex (top compositeness)
- Thinking about both top and bottom asymmetry.

Unfortunately I have to stop here for lunch..............