On Models of New Physics for the Tevatron Top Forward-Backward Asymmetry

Moira Gresham[*]

work in collaboration with

Ian-Woo Kim and Kathryn Zurek
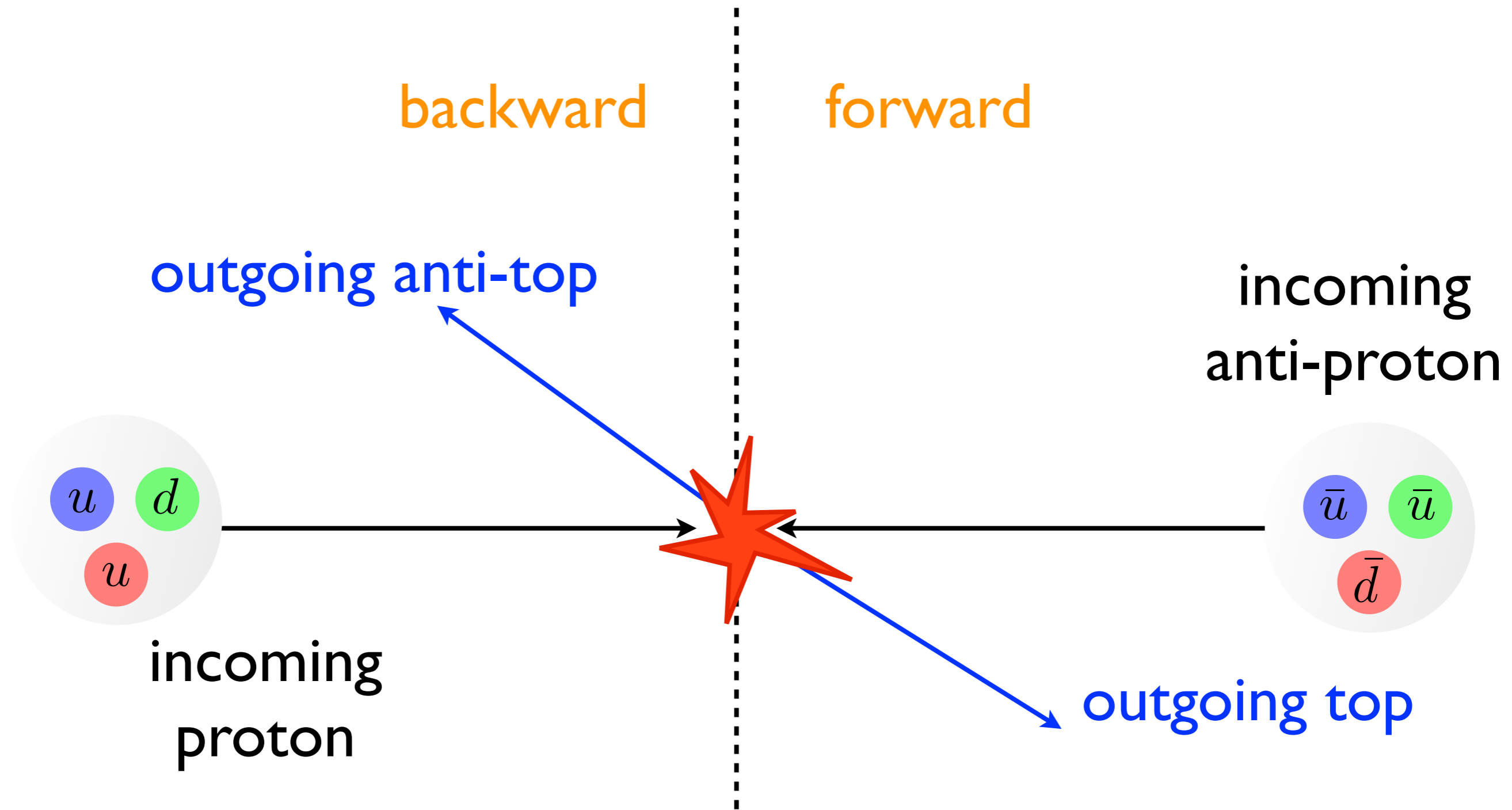
at the University of Michigan

[arXiv:1103.3501]

Pheno 2011 Symposium
May 10, 2011

backward   forward

outgoing anti-top

incoming
anti-proton

u d
u

$\bar{u}$ $\bar{u}$
$\bar{d}$

incoming
proton

outgoing top

top forward-
backward $=$ $\dfrac{(\text{# forward tops}) - (\text{# backward tops})}{\text{total # of tops}}$
Asymmetry
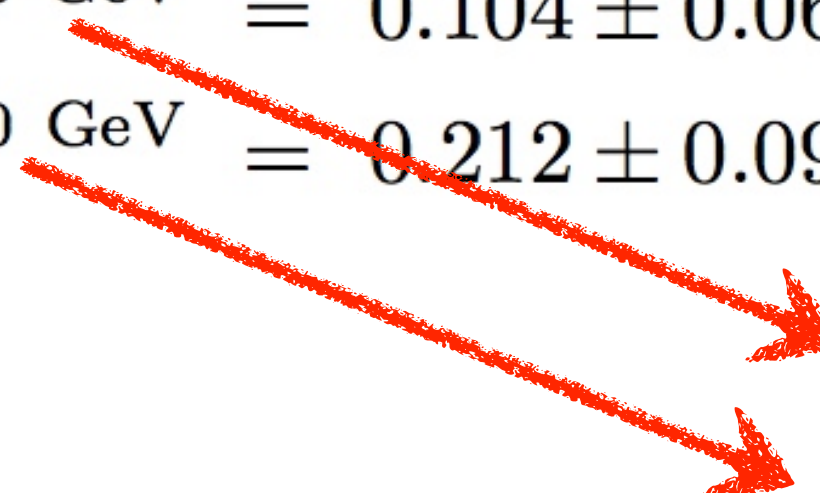
CDF, semileptonic $t\bar{t}$ events [arXiv:1101.0034]

$A^{t\bar{t}}_{FBi}$	$m_{t\bar{t}} < 450$ GeV		$m_{t\bar{t}} > 450$ GeV	
bkd-sub data	$-0.022 \pm 0.039 \pm 0.017$	$\Delta = -0.9\sigma$	$0.266 \pm 0.053 \pm 0.032$	$\Delta = 3.6\sigma$
MC@ NLO	0.015 ± 0.006		0.043 ± 0.009	
parton data	$-0.116 \pm 0.146 \pm 0.047$	$\Delta = -1\sigma$	$0.475 \pm 0.101 \pm 0.049$	$\Delta = 3.4\sigma$
MC@ NLO	0.040 ± 0.006		0.088 ± 0.013	

1260 events passed selection,
283+/- 91 estimated background

Independent confirmation:

Measurement of the Forward Backward Asymmetry in Top Pair Production in the Dilepton Decay Channel using 5.1 /fb (CDF, March 2011)

$$A_{\text{obs}}^{<450\text{ GeV}} = 0.104 \pm 0.066(\text{stat.}) \qquad (\text{Pred.} : 0.003 \pm 0.031)$$

$$A_{\text{obs}}^{>450\text{ GeV}} = 0.212 \pm 0.096(\text{stat.}) \qquad (\text{Pred.} : -0.040 \pm 0.055)$$
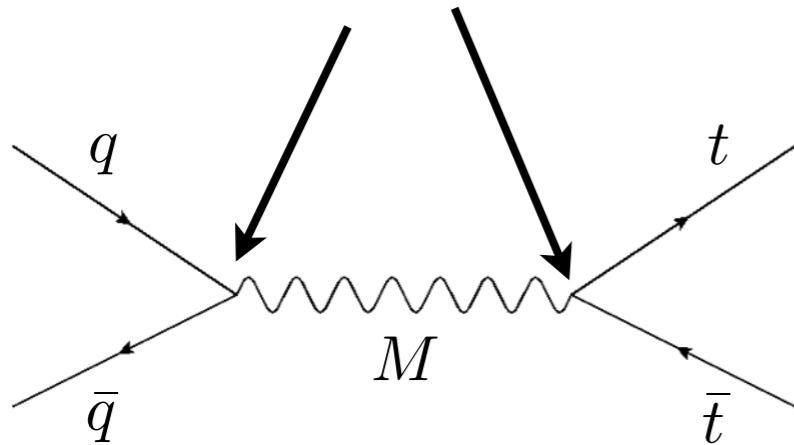
$$\Delta = 1.4\sigma$$

$$\Delta = 2.3\sigma$$

Measurement of the forward-backward production asymmetry of t and $\bar{t}$ quarks in $p\bar{p} \rightarrow t\bar{t}$ events (D0, July 2010)

$$A_{fb} = (8 \pm 4\,(\text{stat}) \pm 1\,(\text{syst}))\,\% \qquad A_{fb}^{pred} = (1^{+2}_{-1}(\text{syst}))\%.$$

How to produce a large asymmetry
(models proposed in literature to "explain" the asymmetry):
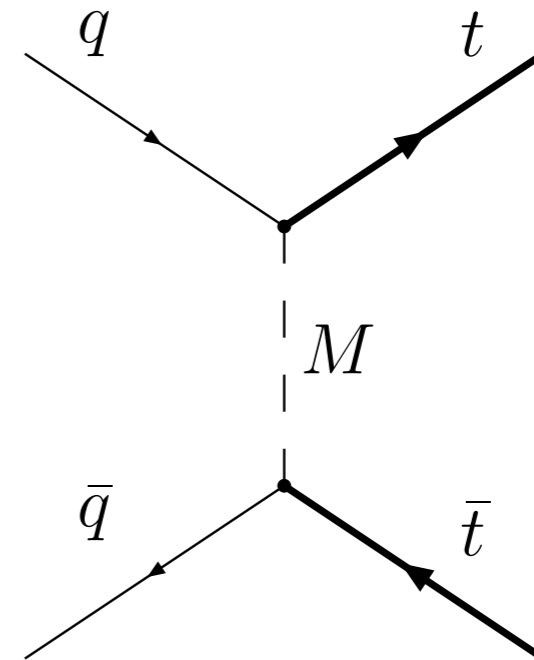
s channel

nonzero axial couplings

vector...
- color octet (with maximally axial couplings to light quarks and to top quarks) aka an axigluon
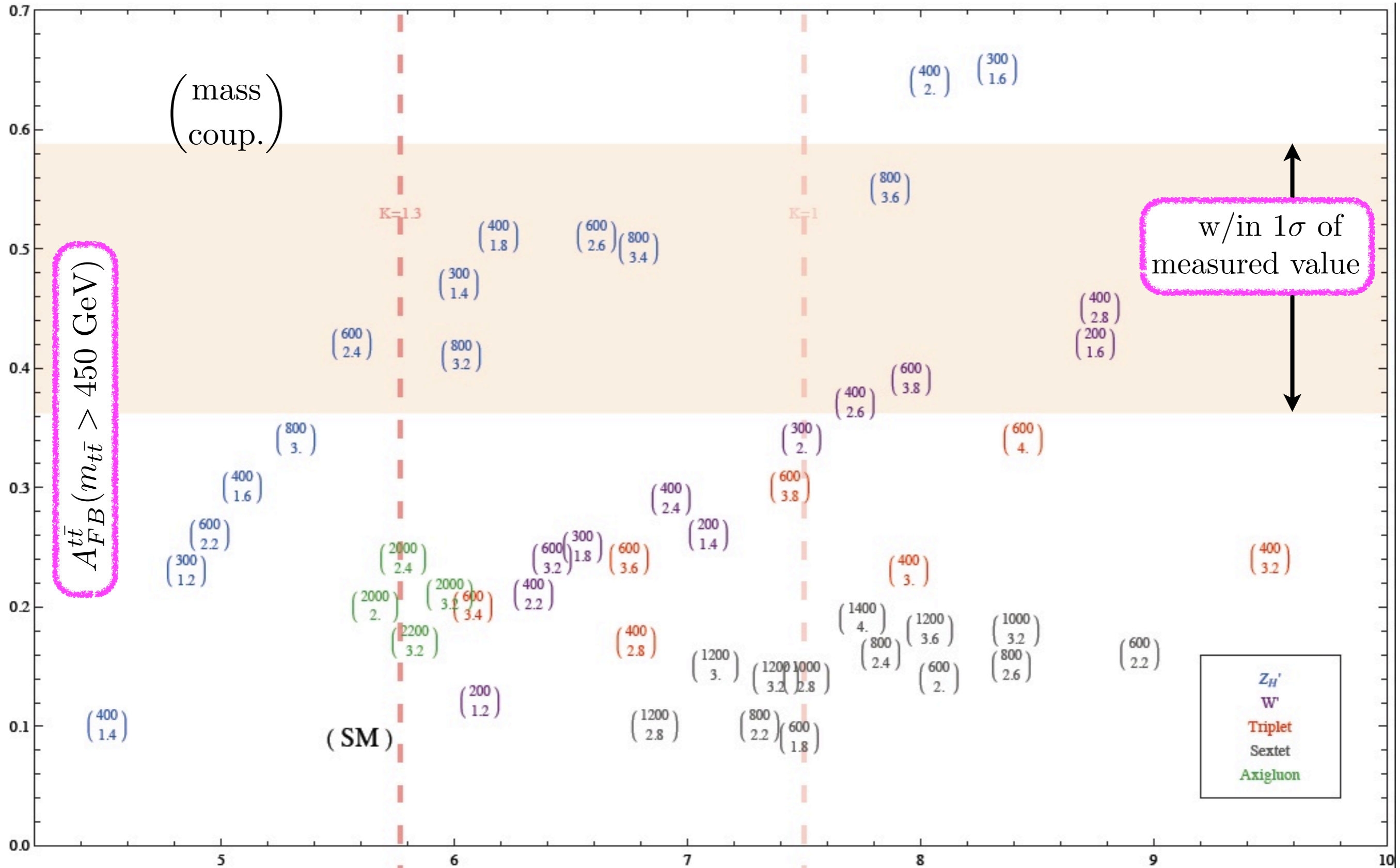- ...

t channel

top flavor-carrying...
- Z' (neutral vector singlet)
- W' (charged vector singlet)
- scalar color anti-triplet
- scalar color sextet
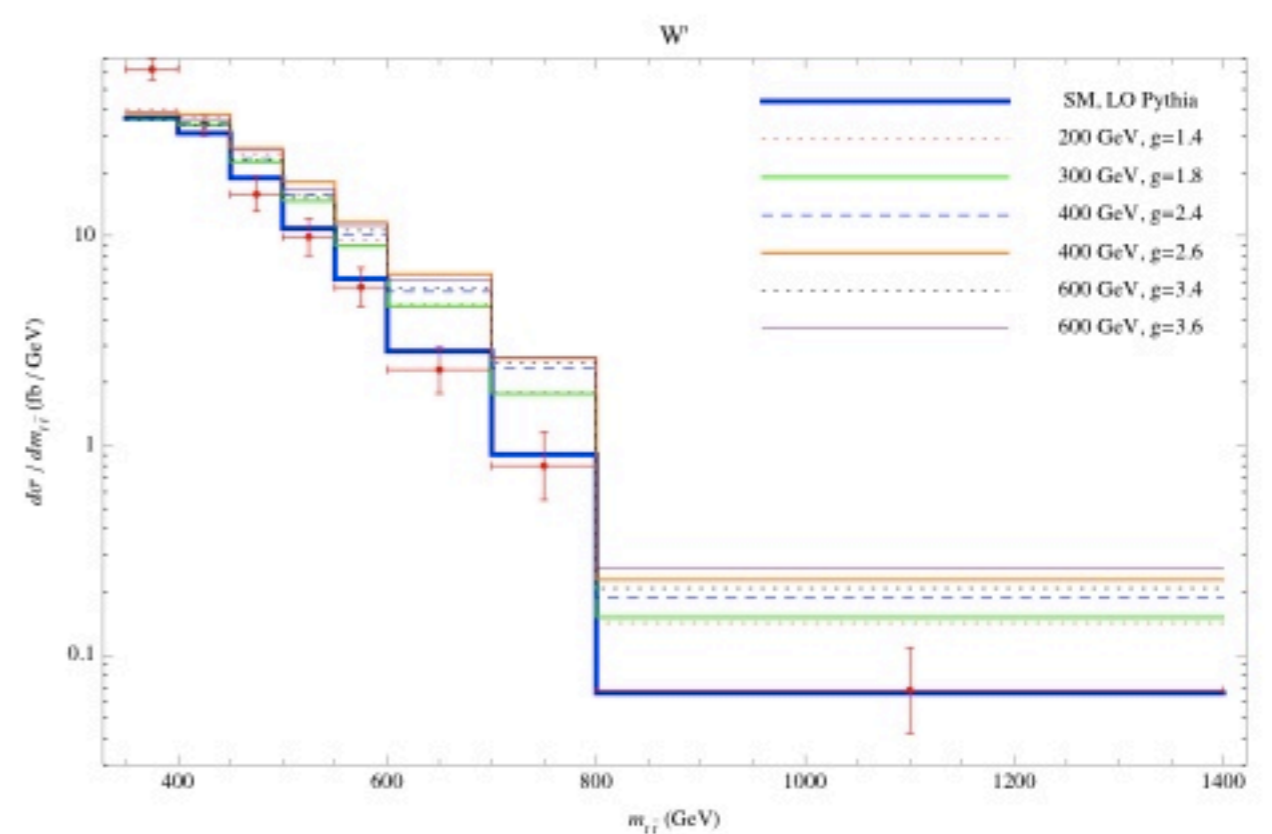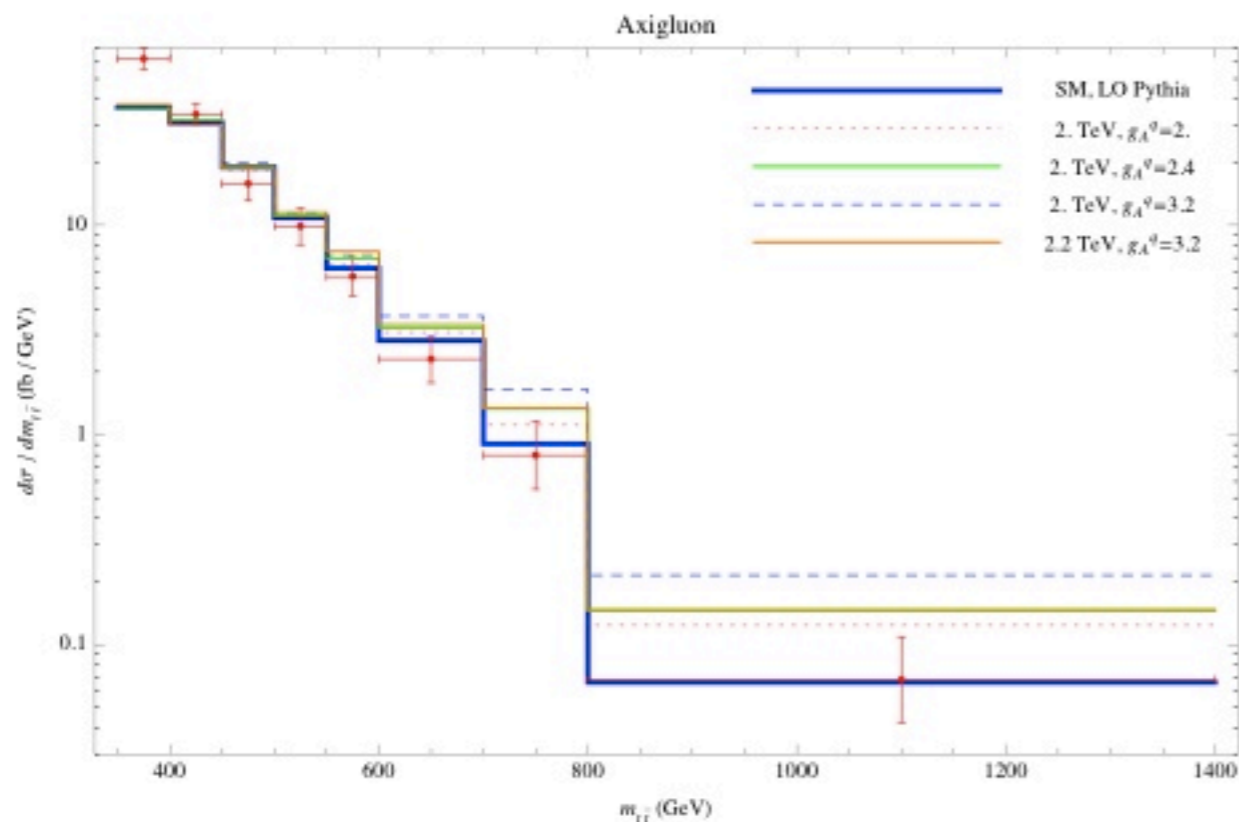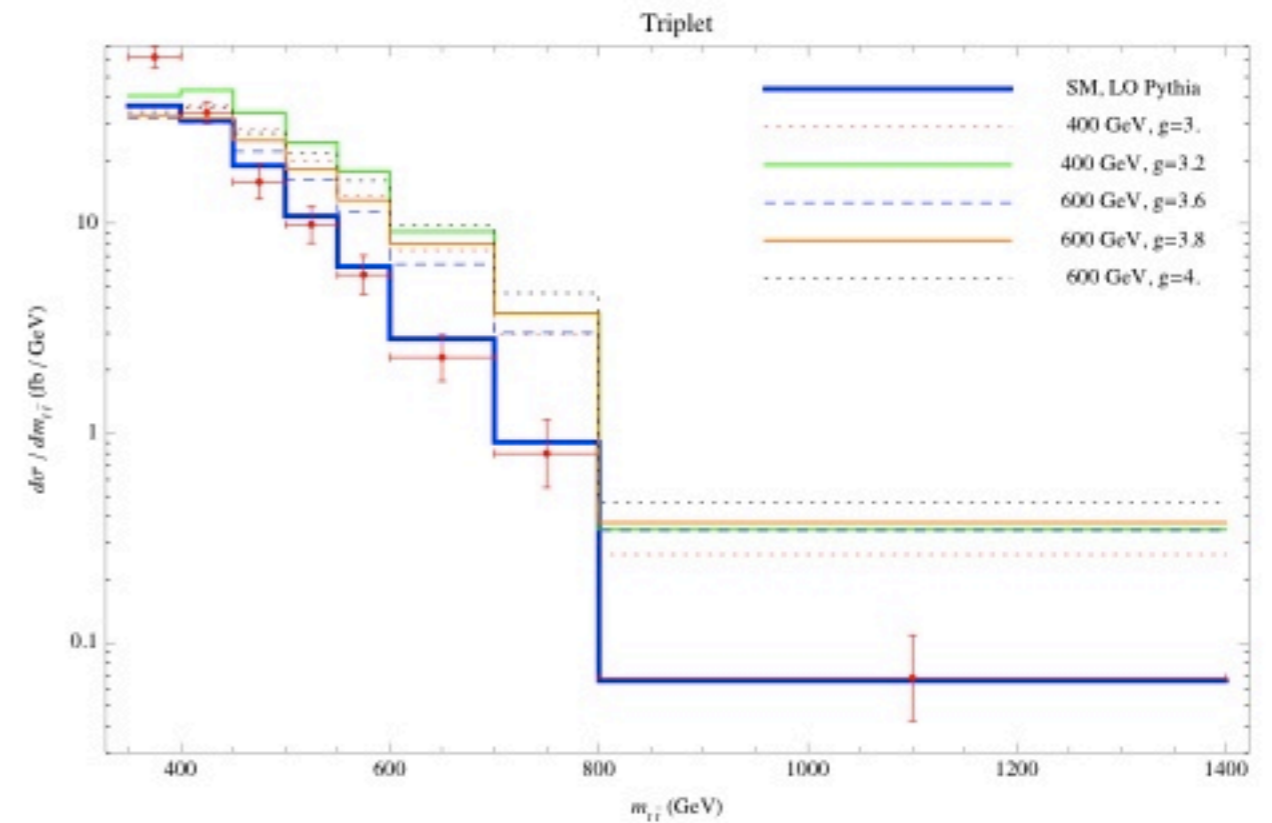- ...

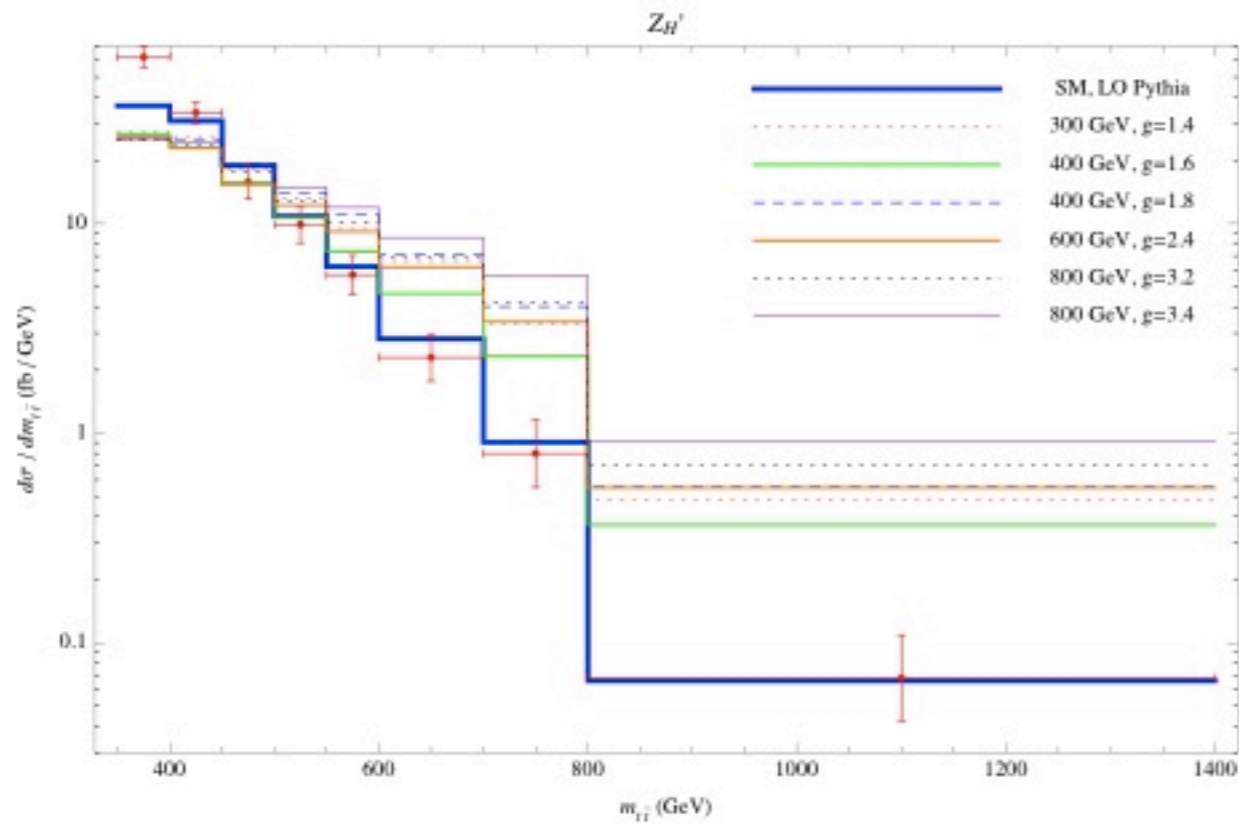(See 1103.3501 for references.)

Main goals:

- Reassess the viability of new physics models proposed to explain the top forward-backward asymmetry in light of new CDF measurements. (Utilizing all of the CDF information requires a full detector simulation and top reconstruction.)

- Investigate subtleties associated with CDF's unfolding of the "raw" asymmetry to a "parton level" asymmetry.

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(mass coup.)

$A_{FB}^{t\bar{t}}(m_{t\bar{t}} > 450 \text{ GeV})$

w/in 1σ of measured value

σ (pb, leading order, no K factor)

(Note large couplings.)

K=1.3

K=1

$\begin{pmatrix} 400 \\ 2. \end{pmatrix}$ $\begin{pmatrix} 300 \\ 1.6 \end{pmatrix}$

$\begin{pmatrix} 800 \\ 3.6 \end{pmatrix}$

$\begin{pmatrix} 400 \\ 1.8 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 2.6 \end{pmatrix}$ $\begin{pmatrix} 800 \\ 3.4 \end{pmatrix}$

$\begin{pmatrix} 300 \\ 1.4 \end{pmatrix}$

$\begin{pmatrix} 400 \\ 2.8 \end{pmatrix}$

$\begin{pmatrix} 600 \\ 2.4 \end{pmatrix}$ $\begin{pmatrix} 800 \\ 3.2 \end{pmatrix}$

$\begin{pmatrix} 200 \\ 1.6 \end{pmatrix}$

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$\begin{pmatrix} 800 \\ 3. \end{pmatrix}$

$\begin{pmatrix} 300 \\ 2. \end{pmatrix}$

$\begin{pmatrix} 600 \\ 4. \end{pmatrix}$

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$\begin{pmatrix} 600 \\ 3.8 \end{pmatrix}$

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$\begin{pmatrix} 400 \\ 2.4 \end{pmatrix}$

$\begin{pmatrix} 300 \\ 1.2 \end{pmatrix}$

$\begin{pmatrix} 2000 \\ 2.4 \end{pmatrix}$

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$\begin{pmatrix} 200 \\ 1.4 \end{pmatrix}$

$\begin{pmatrix} 400 \\ 3. \end{pmatrix}$

$\begin{pmatrix} 400 \\ 3.2 \end{pmatrix}$

$\begin{pmatrix} 2000 \\ 2. \end{pmatrix}$ $\begin{pmatrix} 2000 \\ 3.2 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 3.4 \end{pmatrix}$ $\begin{pmatrix} 400 \\ 2.2 \end{pmatrix}$

$\begin{pmatrix} 2200 \\ 3.2 \end{pmatrix}$

$\begin{pmatrix} 400 \\ 2.8 \end{pmatrix}$

$\begin{pmatrix} 1400 \\ 4. \end{pmatrix}$ $\begin{pmatrix} 1200 \\ 3.6 \end{pmatrix}$ $\begin{pmatrix} 1000 \\ 3.2 \end{pmatrix}$

$\begin{pmatrix} 800 \\ 2.4 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 2. \end{pmatrix}$ $\begin{pmatrix} 800 \\ 2.6 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 2.2 \end{pmatrix}$

$\begin{pmatrix} 1200 \\ 3. \end{pmatrix}$ $\begin{pmatrix} 1200 \\ 3.2 \end{pmatrix}$ $\begin{pmatrix} 1000 \\ 2.8 \end{pmatrix}$

$\begin{pmatrix} 200 \\ 1.2 \end{pmatrix}$

(SM)

$\begin{pmatrix} 1200 \\ 2.8 \end{pmatrix}$ $\begin{pmatrix} 800 \\ 2.2 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 1.8 \end{pmatrix}$

$\begin{pmatrix} 400 \\ 1.4 \end{pmatrix}$

Z_H'
W'
Triplet
Sextet
Axigluon

Parton level differential cross section

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Event distribution densities:

CDF cuts include:
- $|\eta_{\text{lep}}| < 1$
- $|\eta_{\text{jet}}| < 2$
- $|\eta_{\text{b-jet}}| < 1$

LO Standard Model

η_{top}

$|\eta_t| < 1$

$m_{t\bar{t}}$
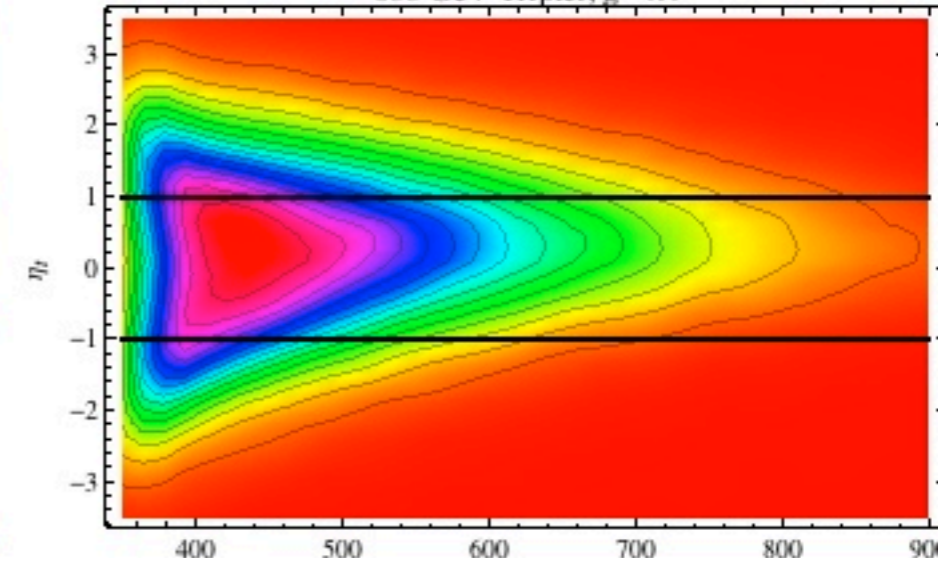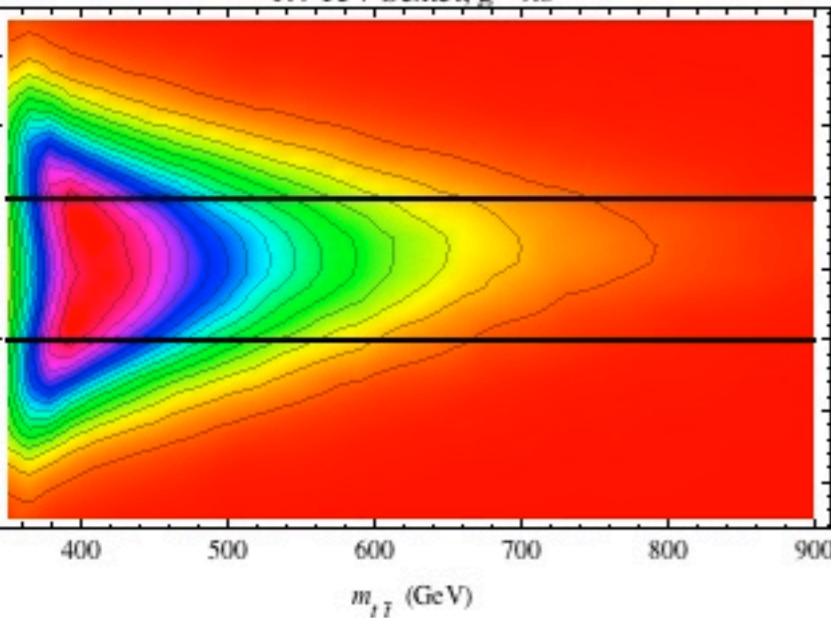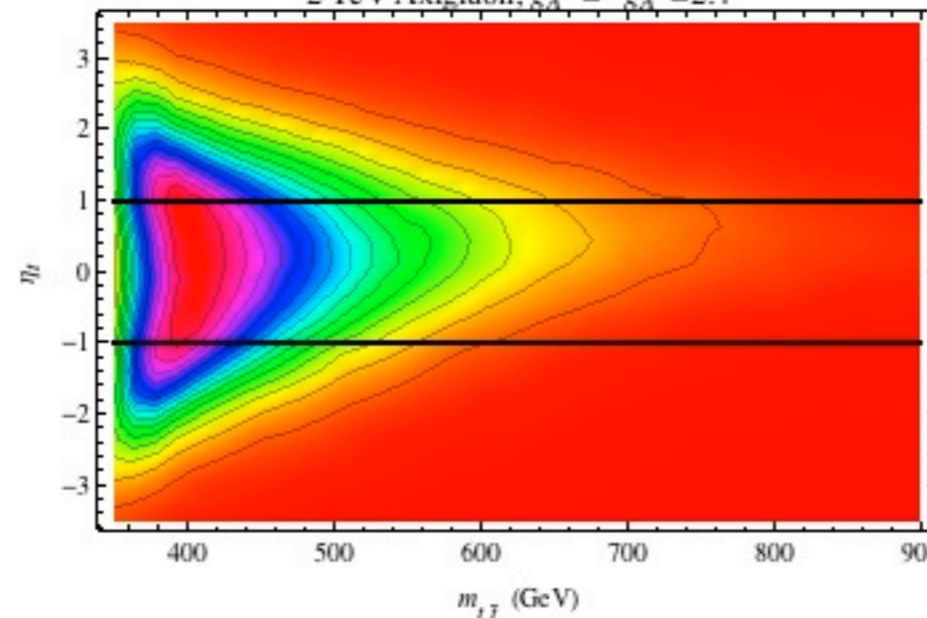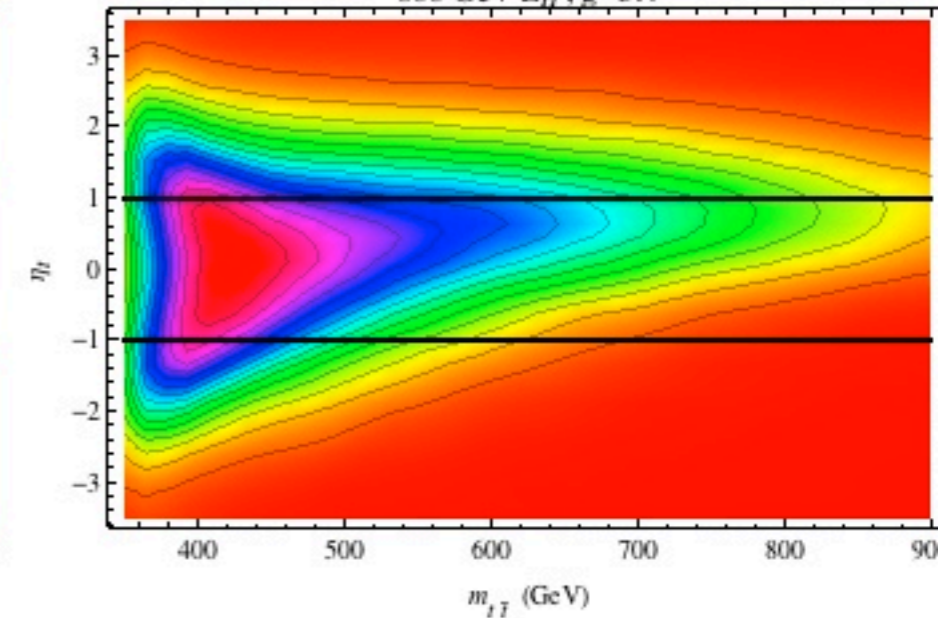
400 GeV Z_H', g=1.75
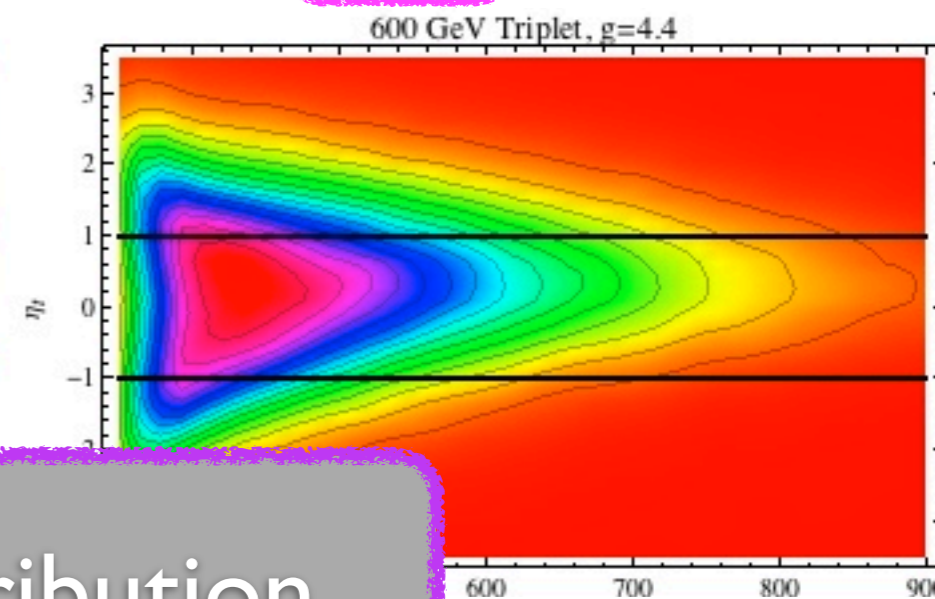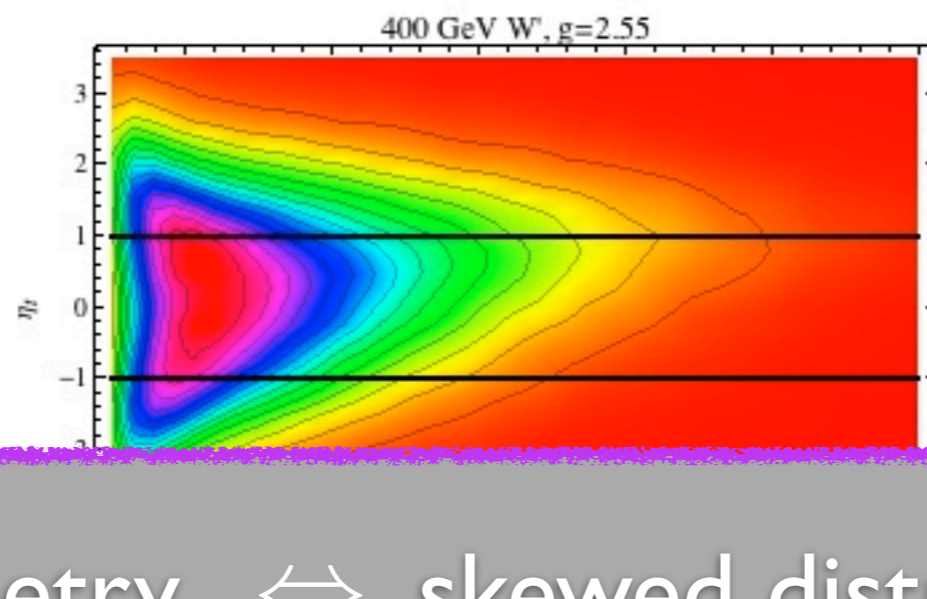
400 GeV W', g=2.55

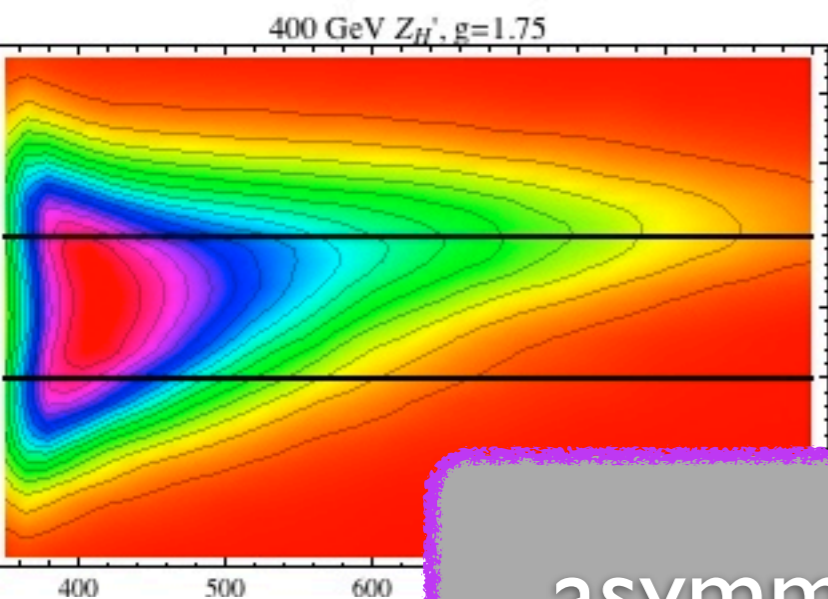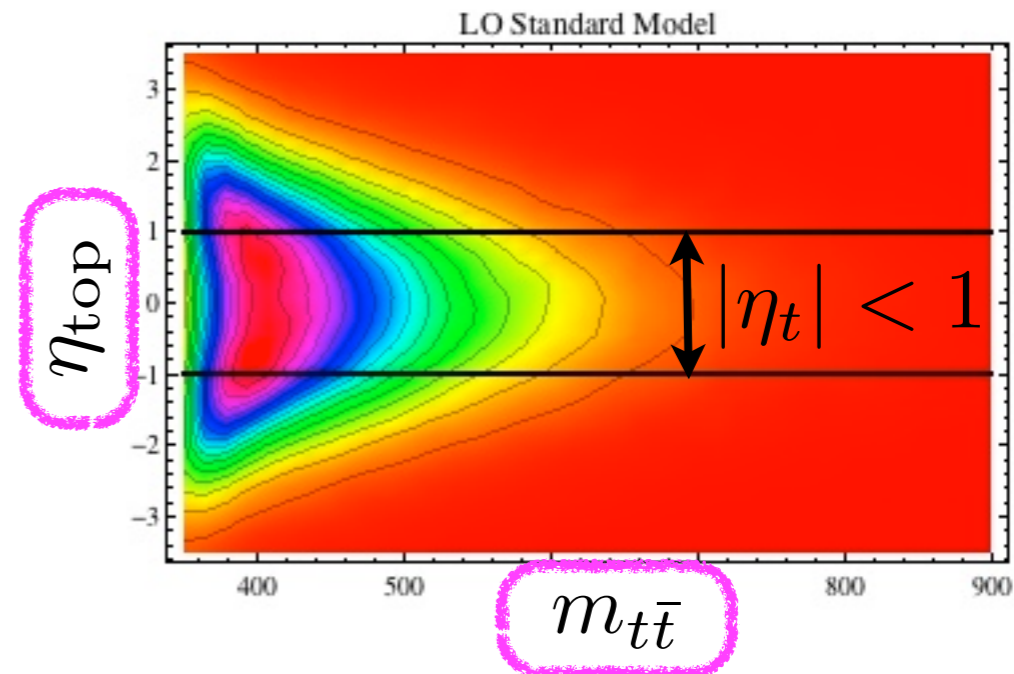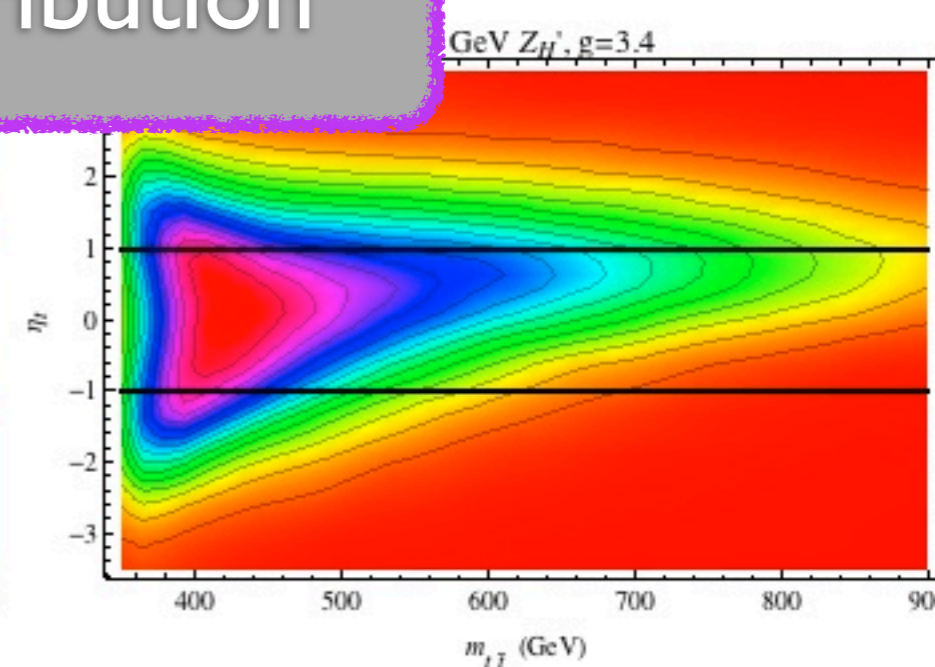600 GeV Triplet, g=4.4

1.4 TeV Sextet, g=4.0

2 TeV Axigluon, $g_A^q = -g_A^t = 2.4$

800 GeV Z_H', g=3.4

$m_{t\bar{t}}$ (GeV)

Moira Gresham

Event distribution densities:

CDF cuts include:
- $|\eta_{\mathrm{lep}}| < 1$
- $|\eta_{\mathrm{jet}}| < 2$
- $|\eta_{\mathrm{b\text{-}jet}}| < 1$

LO Standard Model

η_{top}

$|\eta_t| < 1$

$m_{t\bar{t}}$
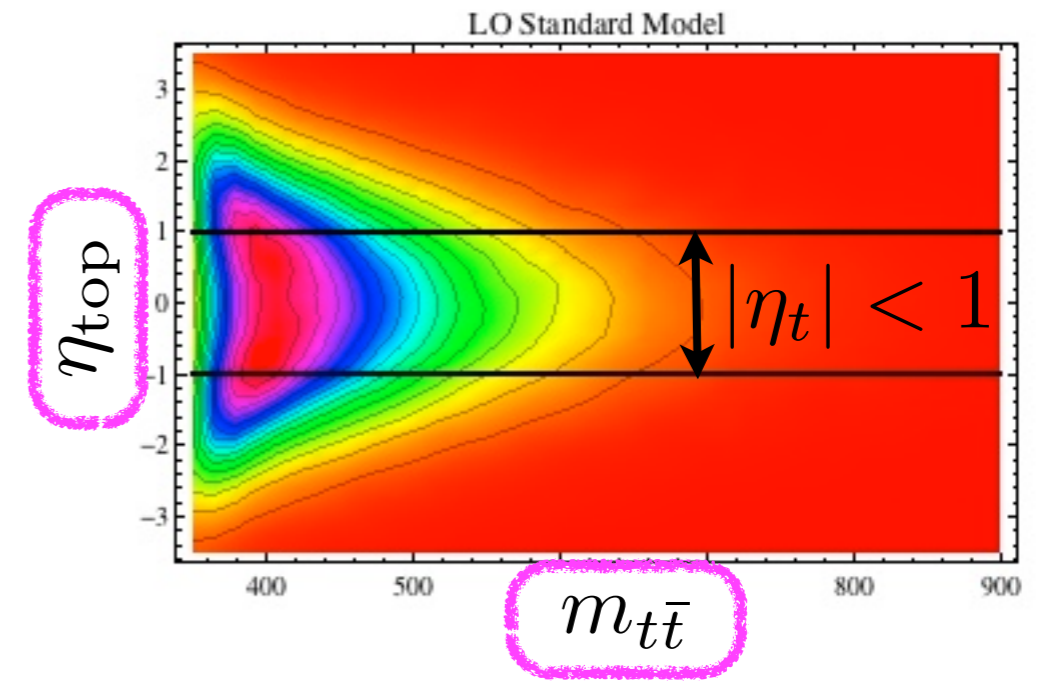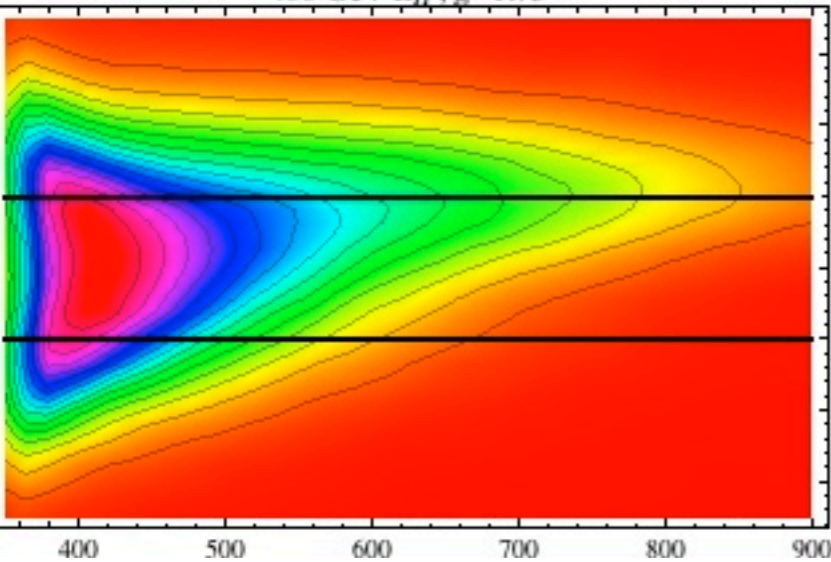
400 GeV Z_H', g=1.75

400 GeV W', g=2.55
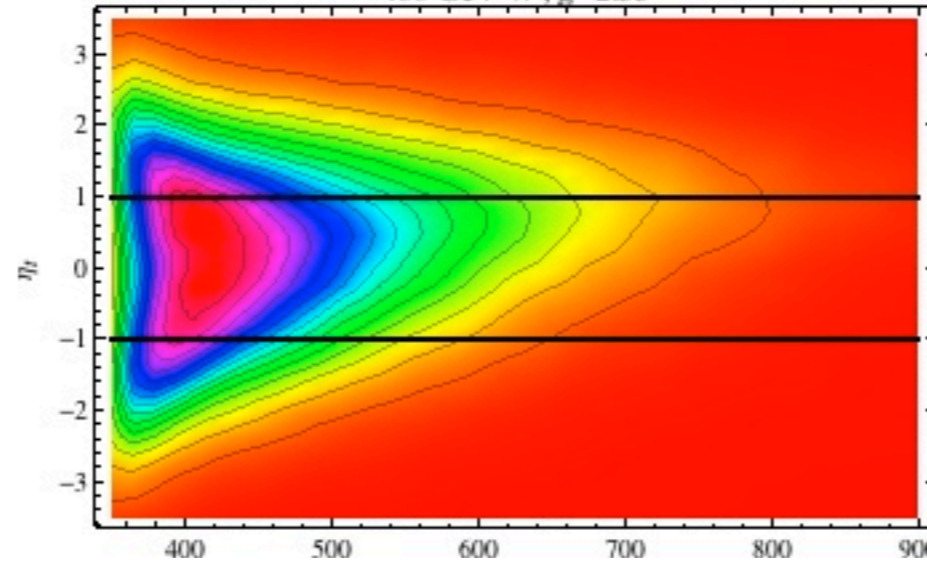
600 GeV Triplet, g=4.4

asymmetry $\Leftrightarrow$ skewed distribution

1.4 TeV Sex

GeV Z_H', g=3.4

η_t

$m_{t\bar{t}}$ (GeV)

$m_{t\bar{t}}$ (GeV)

$m_{t\bar{t}}$ (GeV)
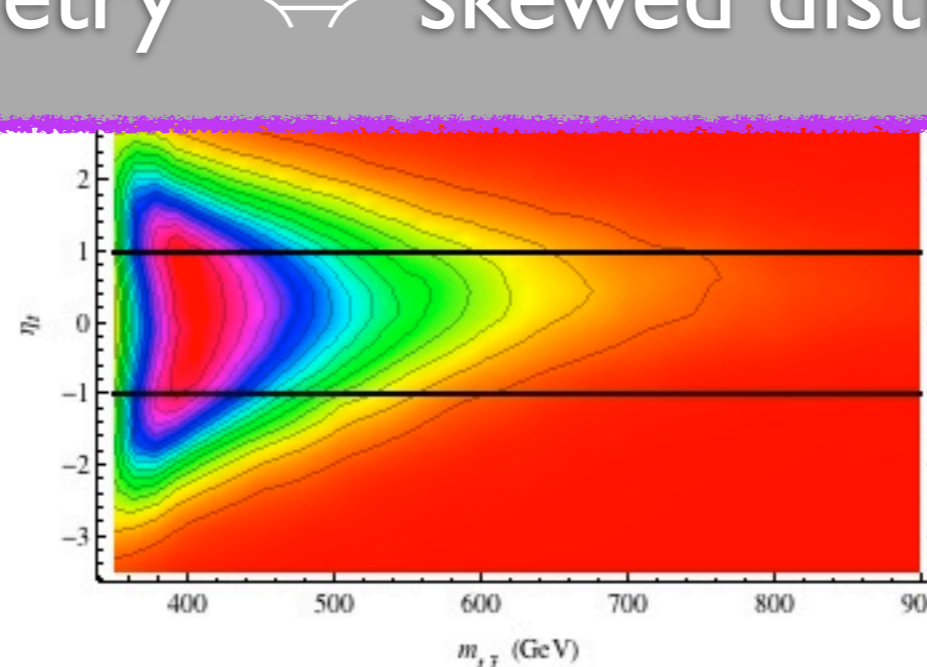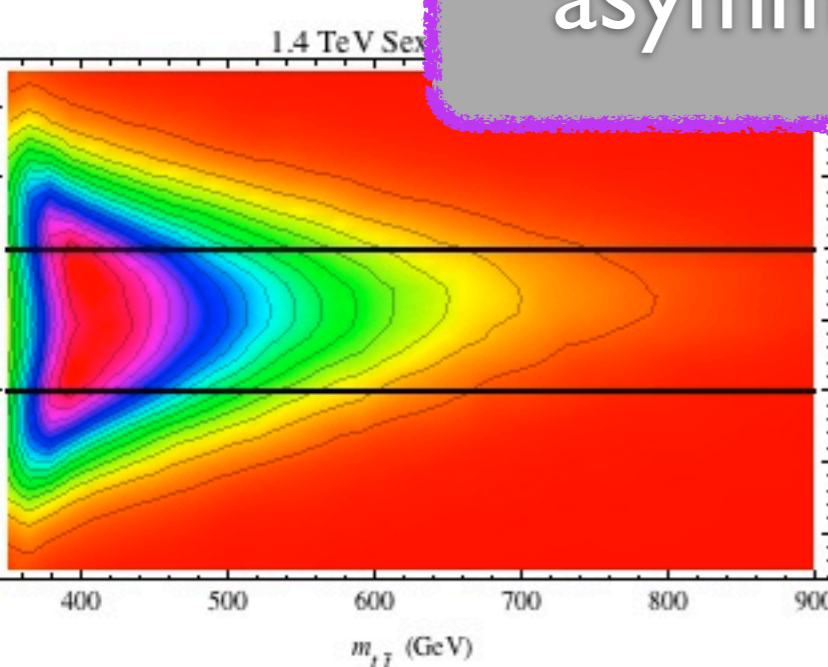
benchmark models (piped through Pythia/PGS, tops reconstructed)

$A^{t\bar{t}}_{FB}(m_{t\bar{t}} > 450 \text{ GeV})$

σ (pb, leading order, no K factor)

$\begin{pmatrix} \text{mass} \\ \text{coup.} \end{pmatrix}$

K=1.3   K=1

$\begin{pmatrix} 800 \\ 3.6 \end{pmatrix}$

$\begin{pmatrix} 400 \\ 1.8 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 2.6 \end{pmatrix}$ $\begin{pmatrix} 800 \\ 3.4 \end{pmatrix}$

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$\begin{pmatrix} 400 \\ 2.8 \end{pmatrix}$

$\begin{pmatrix} 600 \\ 2.4 \end{pmatrix}$ $\begin{pmatrix} 800 \\ 3.2 \end{pmatrix}$ $\begin{pmatrix} 200 \\ 1.6 \end{pmatrix}$

$\begin{pmatrix} 400 \\ 2.6 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 3.8 \end{pmatrix}$

$\begin{pmatrix} 800 \\ 3. \end{pmatrix}$ $\begin{pmatrix} 200 \\ 2 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 4. \end{pmatrix}$

$\begin{pmatrix} 400 \\ 1.6 \end{pmatrix}$ $\begin{pmatrix} 400 \\ 2.4 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 3.8 \end{pmatrix}$

$\begin{pmatrix} 600 \\ 2.2 \end{pmatrix}$ $\begin{pmatrix} 2000 \\ 2.4 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 3.2 \end{pmatrix}\begin{pmatrix} 300 \\ 1.8 \end{pmatrix}$ $\begin{pmatrix} 200 \\ 1.4 \end{pmatrix}$ $\begin{pmatrix} 600 \\ 3.6 \end{pmatrix}$ $\begin{pmatrix} 400 \\ 3.2 \end{pmatrix}$

$\begin{pmatrix} 300 \\ 1.2 \end{pmatrix}$ $\begin{pmatrix} 2000 \\ 2. \end{pmatrix}$ $\begin{pmatrix} 2000 \\ 3.2 \end{pmatrix}\begin{pmatrix} 600 \\ 3.4 \end{pmatrix}$ $\begin{pmatrix} 400 \\ 2.2 \end{pmatrix}$ $\begin{pmatrix} 400 \\ 3. \end{pmatrix}$

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$\begin{pmatrix} 200 \\ 1.2 \end{pmatrix}$ $\begin{pmatrix} 1200 \\ 3. \end{pmatrix}$ $\begin{pmatrix} 1200 \\ 3.2 \end{pmatrix}\begin{pmatrix} 1000 \\ 2.8 \end{pmatrix}$

$\begin{pmatrix} 400 \\ 1.4 \end{pmatrix}$ (SM) $\begin{pmatrix} 1200 \\ 2.8 \end{pmatrix}$ $\begin{pmatrix} 800 \\ 2.2 \end{pmatrix}\begin{pmatrix} 600 \\ 1.8 \end{pmatrix}$

$z_H{}'$
W'
Triplet
Sextet
Axigluon

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Conclusions after data level comparison:

- Z' and W' benchmark models do the best at matching the mass-dependent asymmetry data, though the axigluon and triplet benchmarks don't look so bad.

- None of the benchmark models get the frame-dependent asymmetry quite right.

- The invariant mass spectrum for triplet and high mass Z' events differs substantially from the CDF measurement.

- The invariant mass spectrum for the low mass Z' and W' benchmark events agrees reasonably well with measurement at high invariant mass (lower acceptance in high mass bins seems to have saved them).

Final comments:

- Of models (studied here) that can generate a large asymmetry in the high invariant mass bin, Z' and W' models are the only ones that do not severely overproduce the total ttbar cross section.

- Acceptances for models that produce the asymmetry can be quite different from SM-like acceptances. Care must be taken in comparing to experimental results.

- Due to the order one couplings in these models, higher order corrections will need to be understood before definitive statements can be made.

- Results from the Tevatron are hinting that top physics at the LHC could be very interesting even in early running. See e.g. arXiv: 1102.0018 on expected signals of new t-channel physics.

Backup Slides

Mass-dependent asymmetry unfolding

$$\vec{n}_{\text{signal}} = \mathbf{S}\mathbf{A}\vec{n}_{\text{parton}}$$

$-\quad \Delta y \quad +$

n_{LB}	n_{LF}
n_{HB}	n_{HF}

$m_{t\bar{t}}$
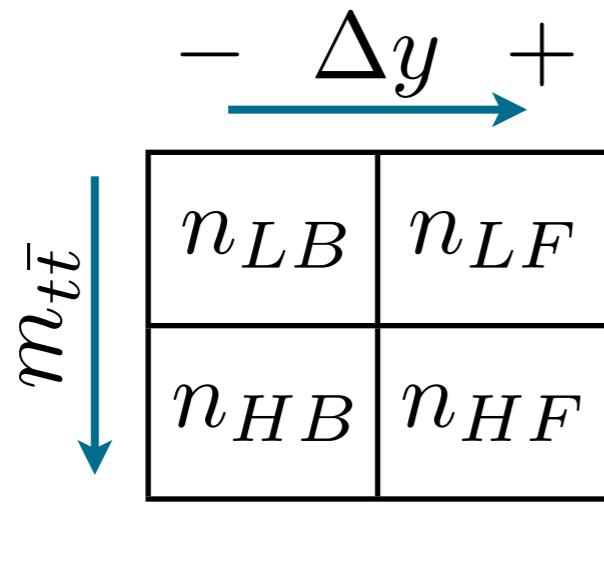
$\mathbf{A}$: Acceptance (diagonal)

$\mathbf{S}$: bin-to-bin migration

(derived through simulations (of SM events... and checked against axigluon events). CAUTION)

$$\vec{n}_{\text{parton}}^{\text{CDF}} = \mathbf{A}_{\text{SM}}^{-1}\mathbf{S}_{\text{SM}}^{-1}(\vec{n}_{\text{data}} - \vec{n}_{\text{bkg}})$$

Comprehensive scan.
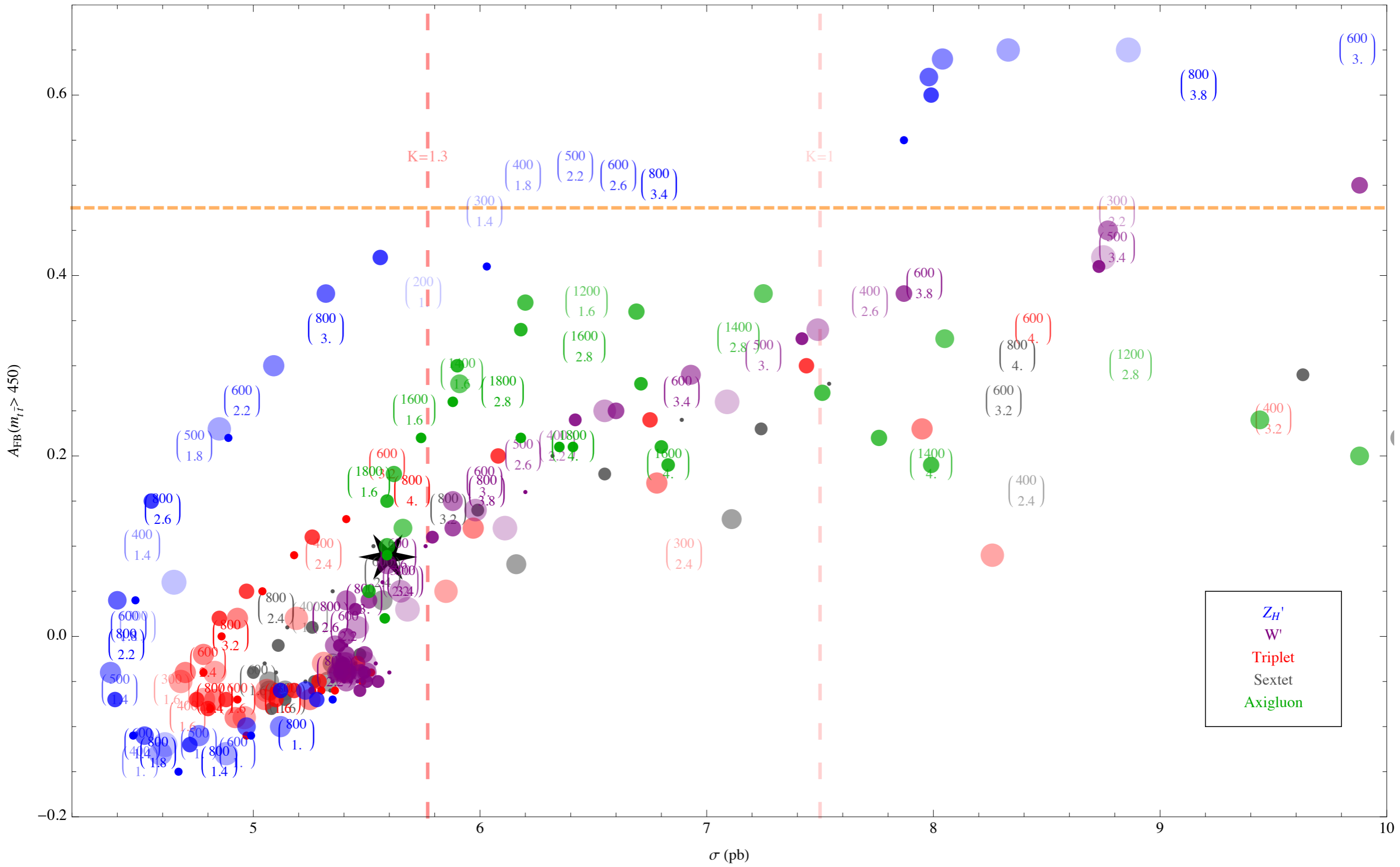
But... differential cross-section measurement assumes SM-like acceptances.

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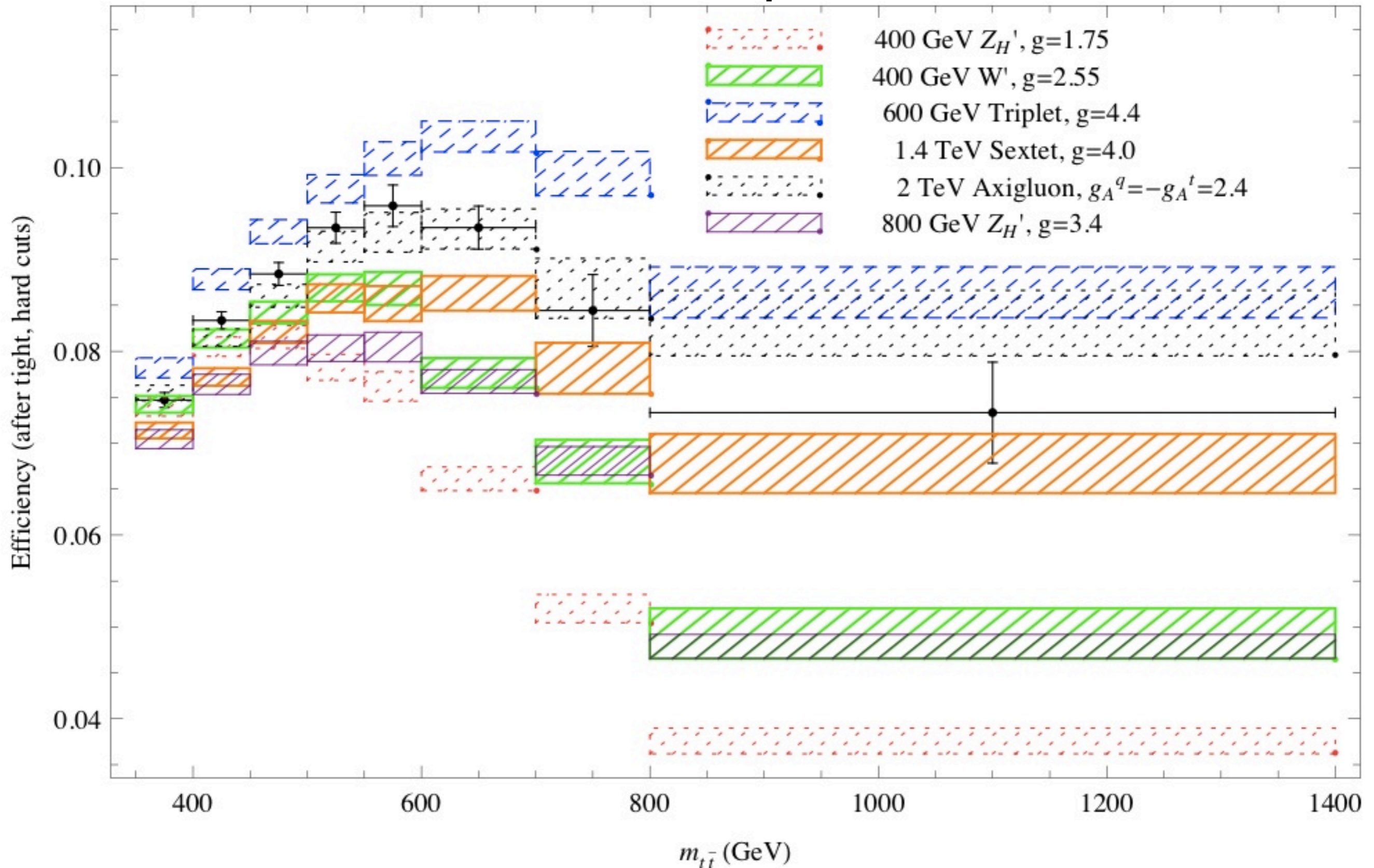
Parton level mass- and rapidity-dependent asymmetries
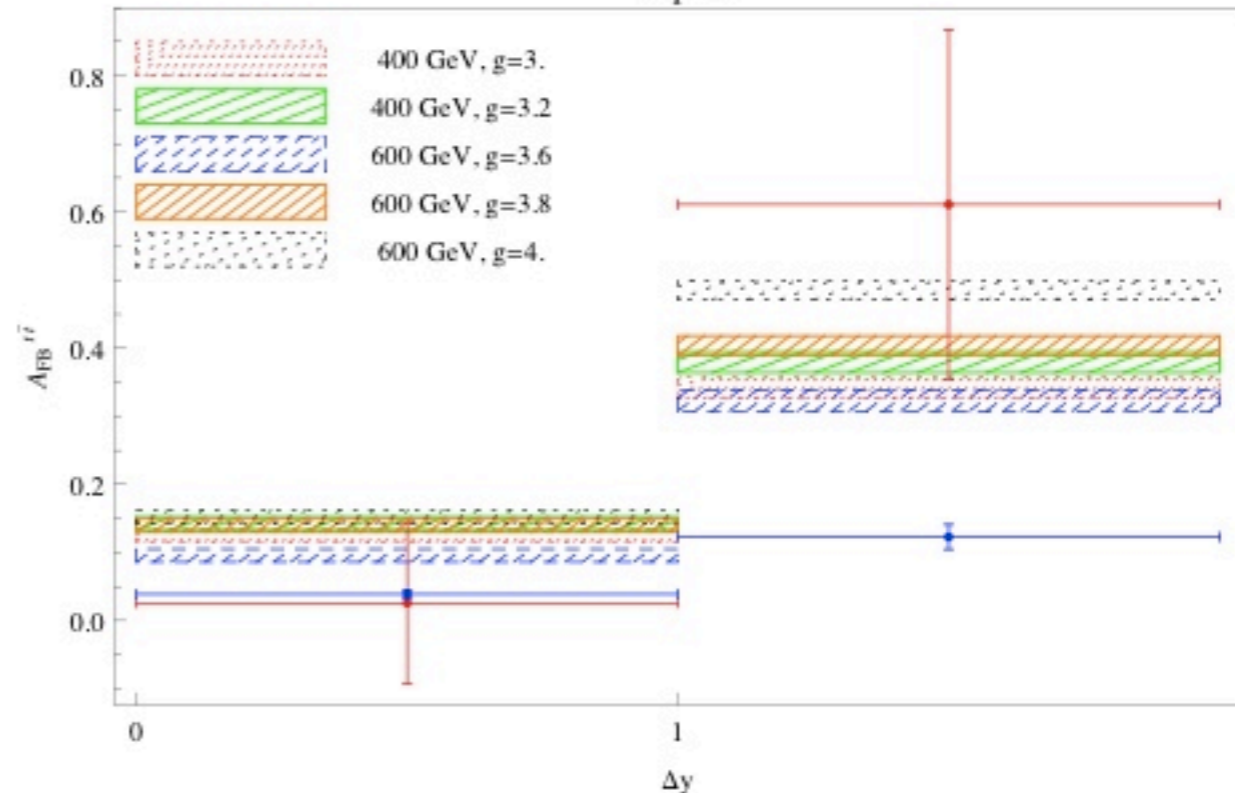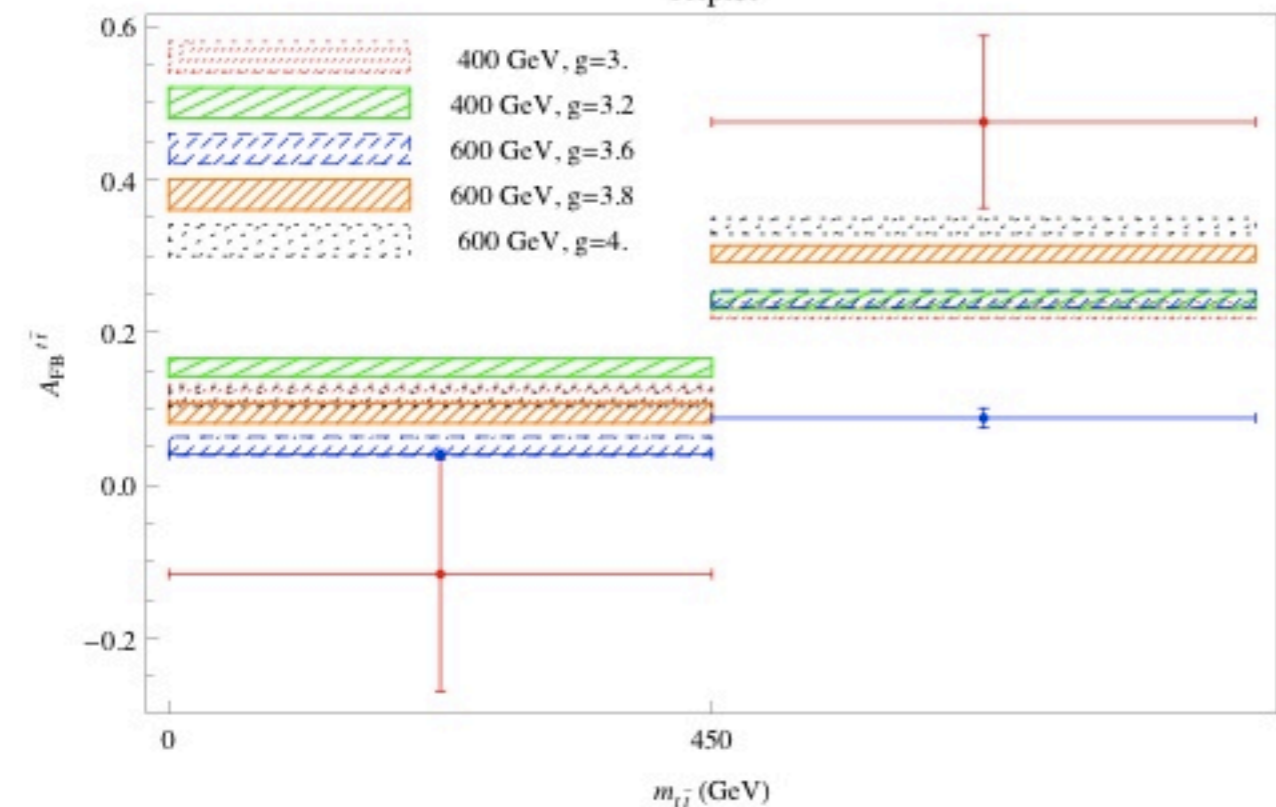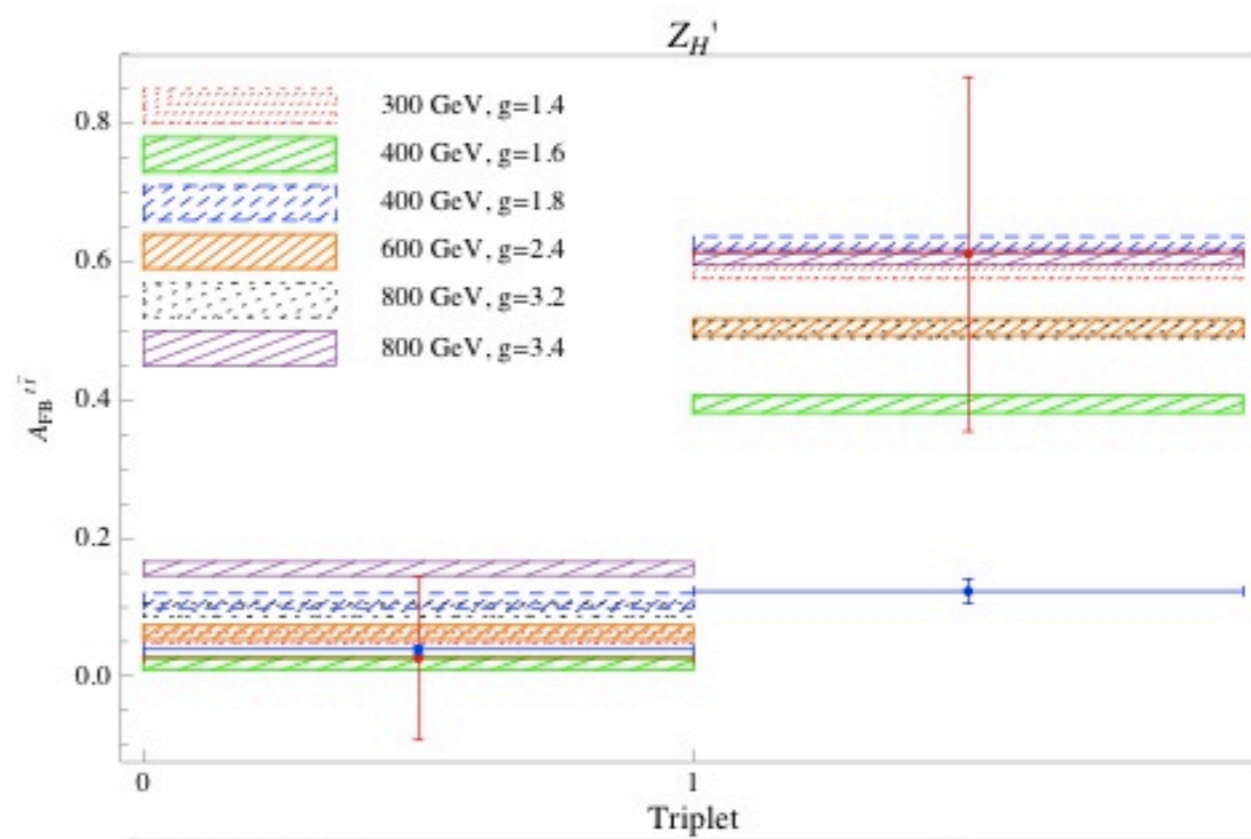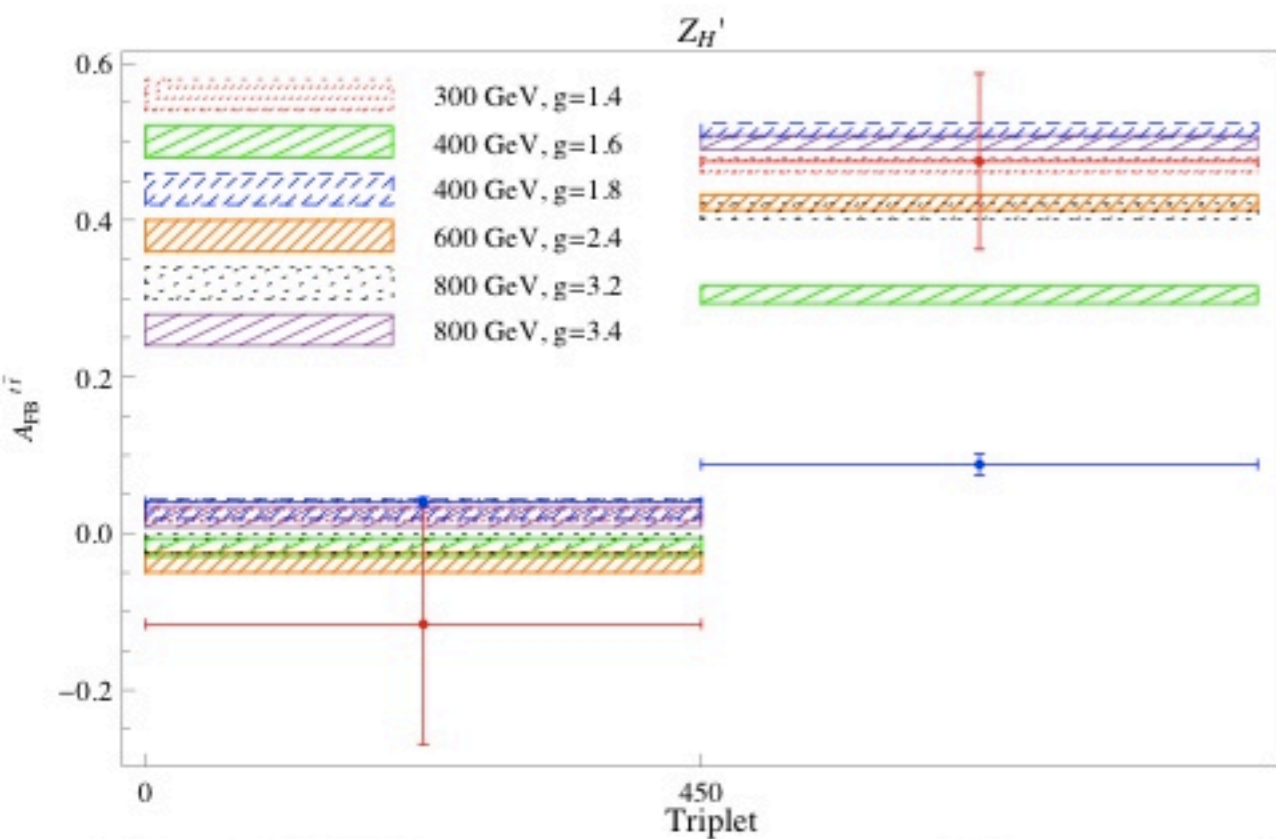
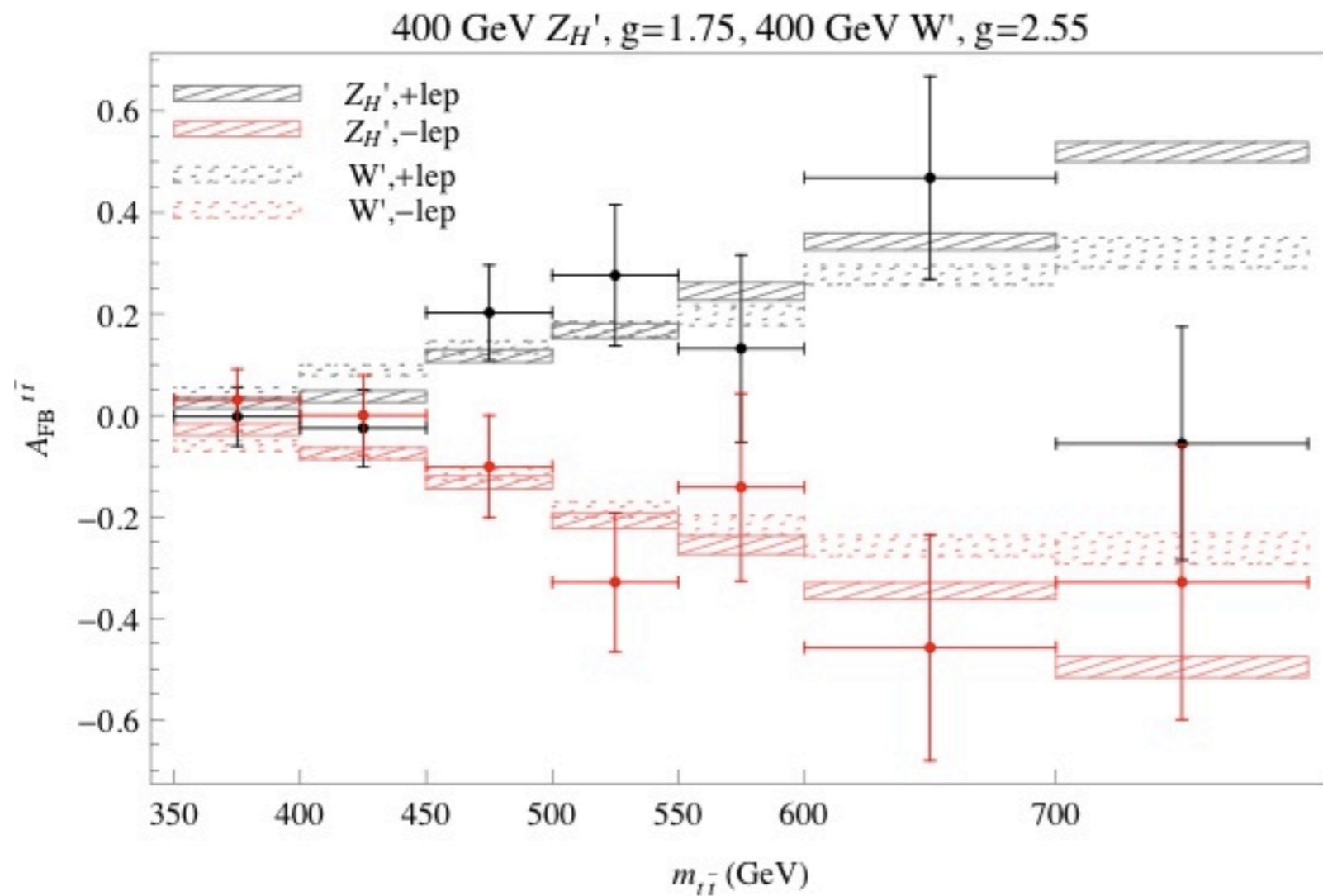# Parton level mass- and rapidity-dependent asymmetries
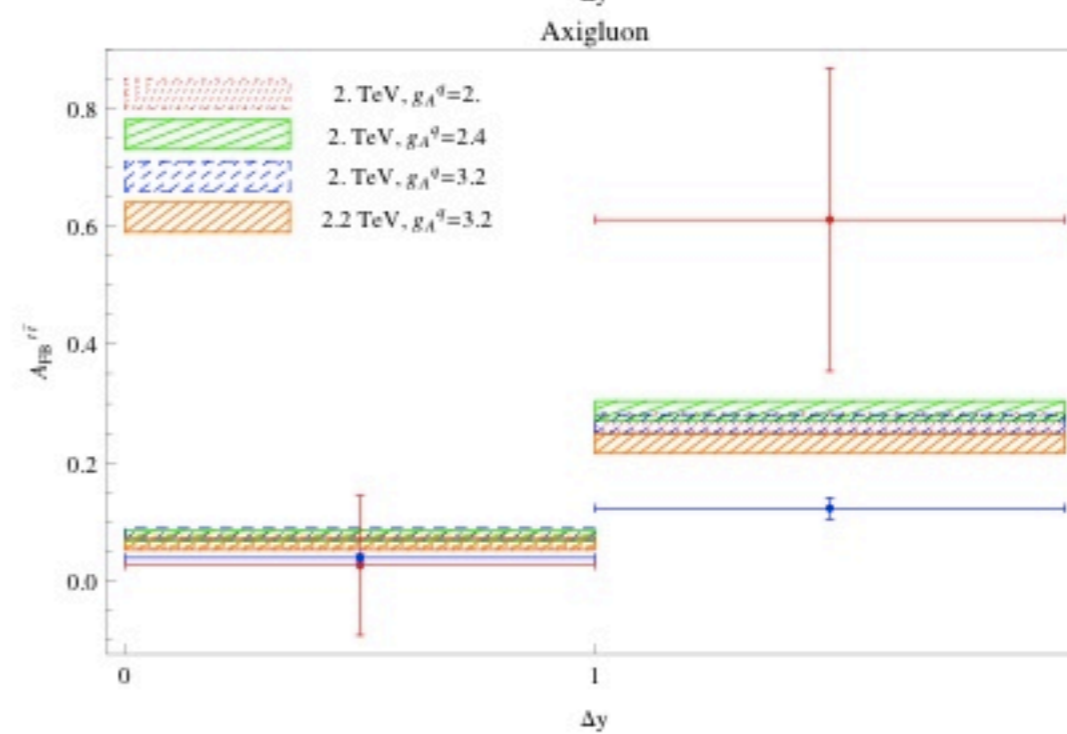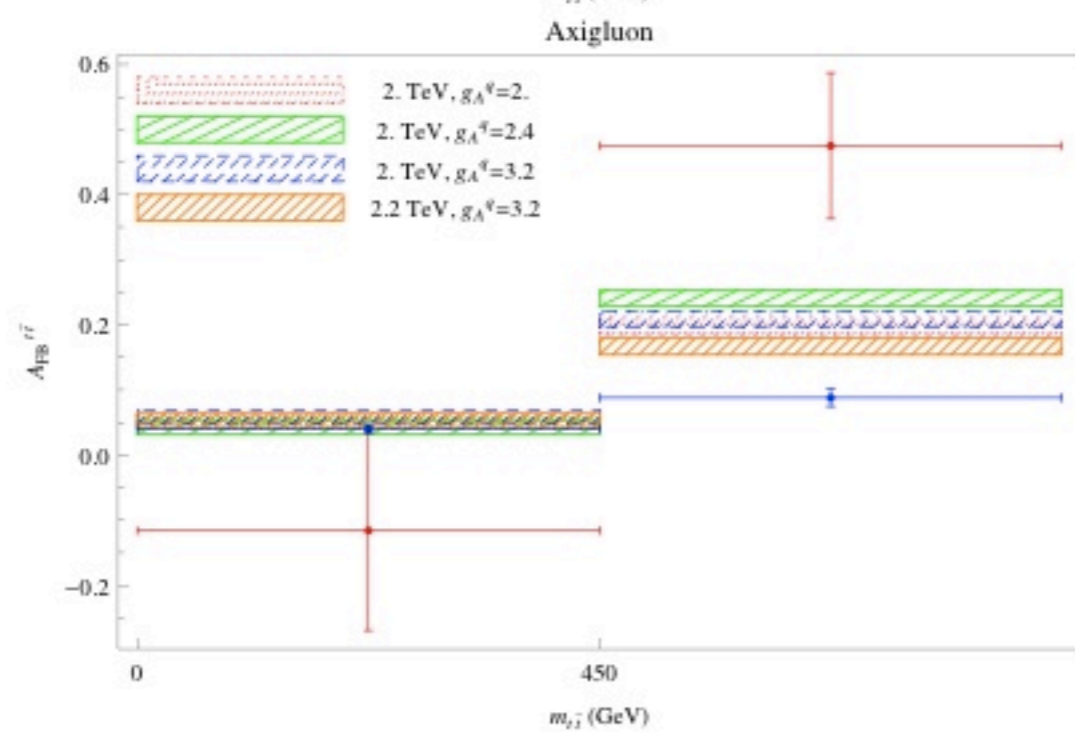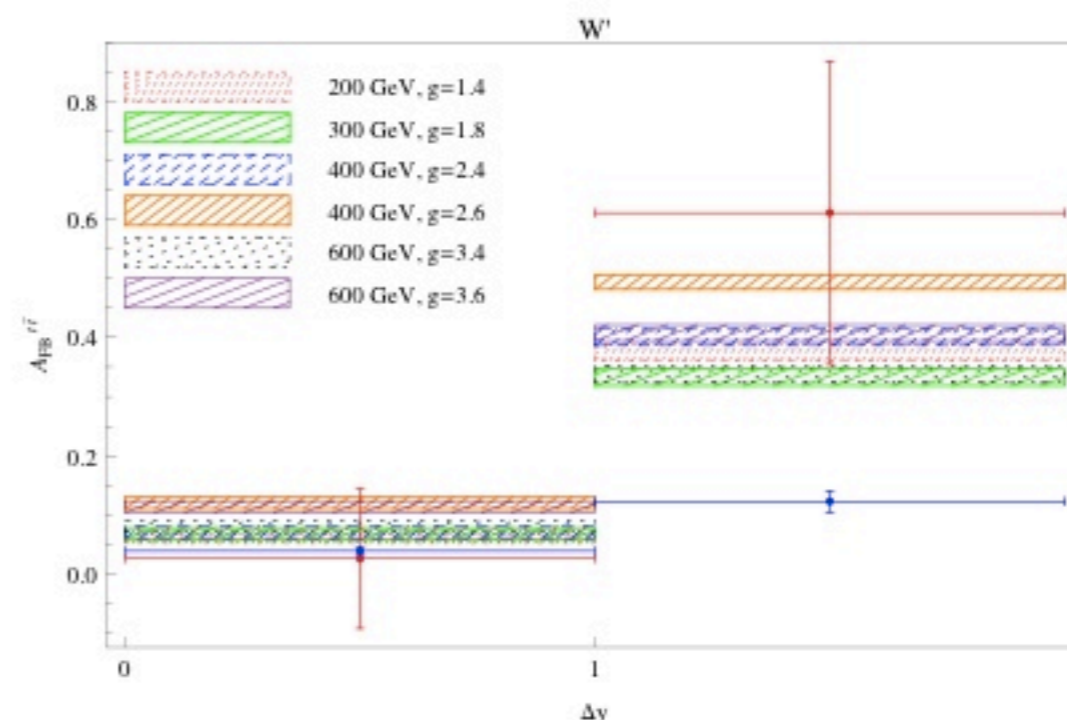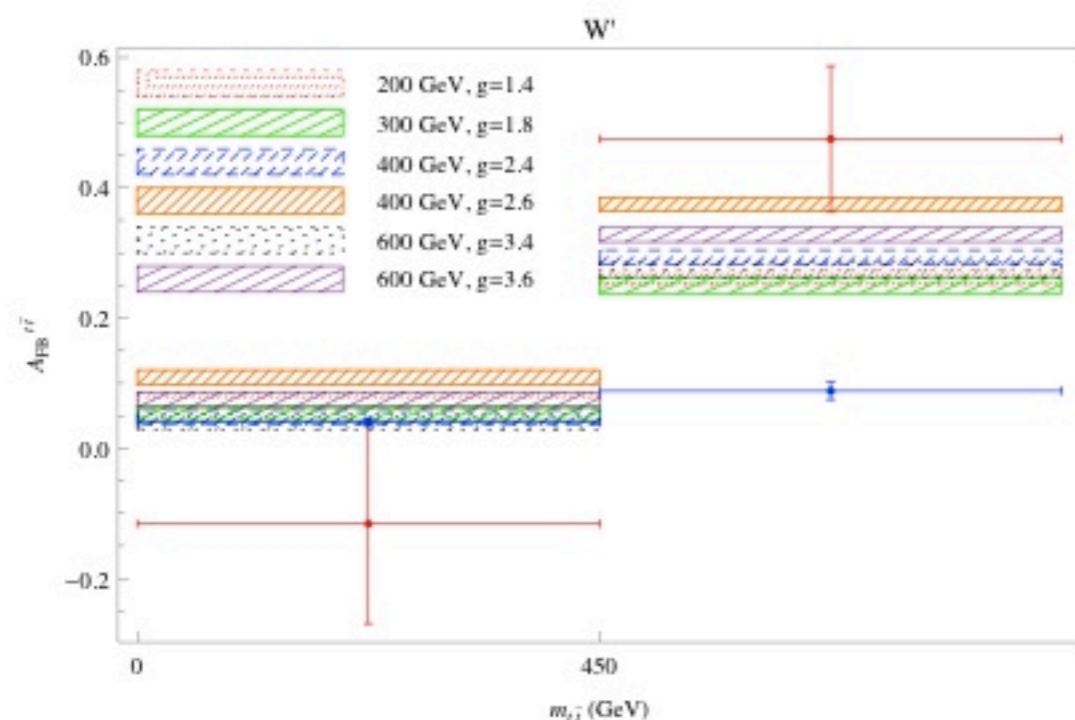
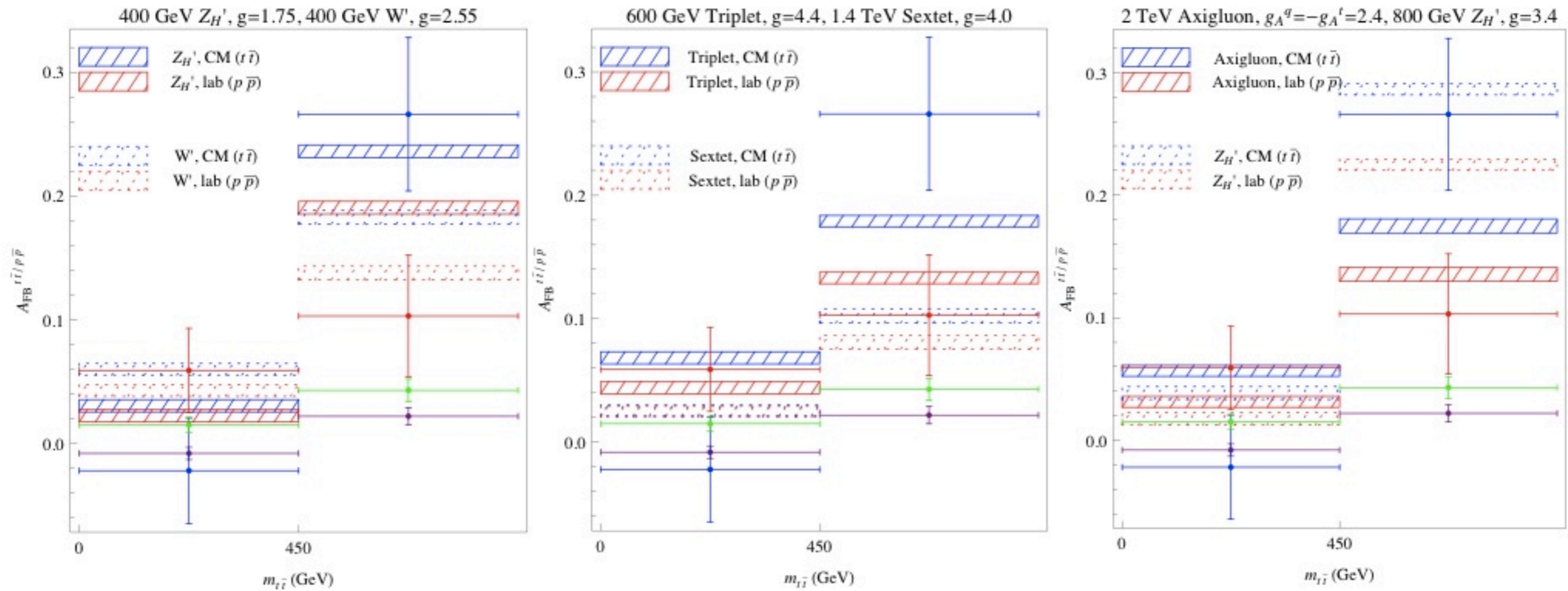# CM frame mass-dependent asymmetry (reconstructed events)
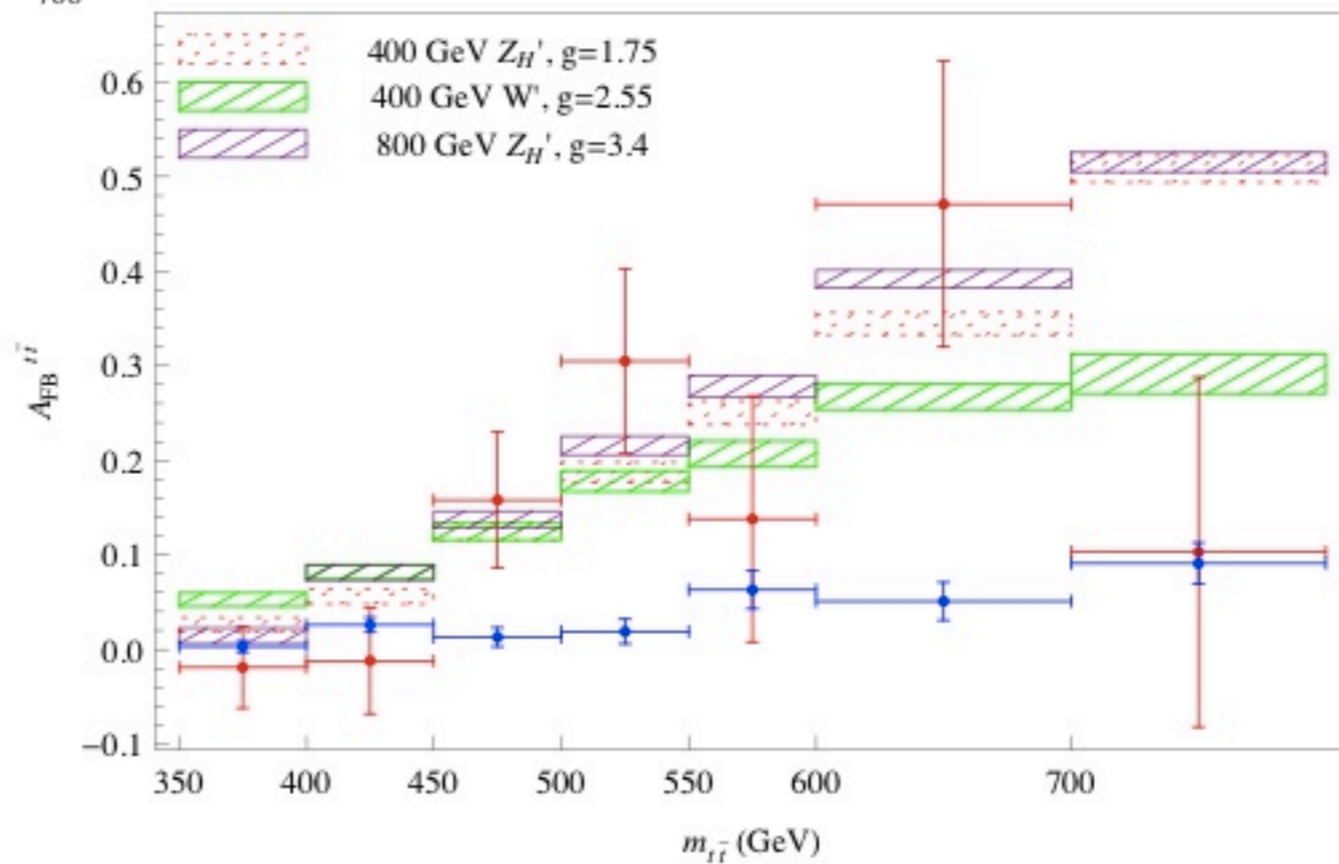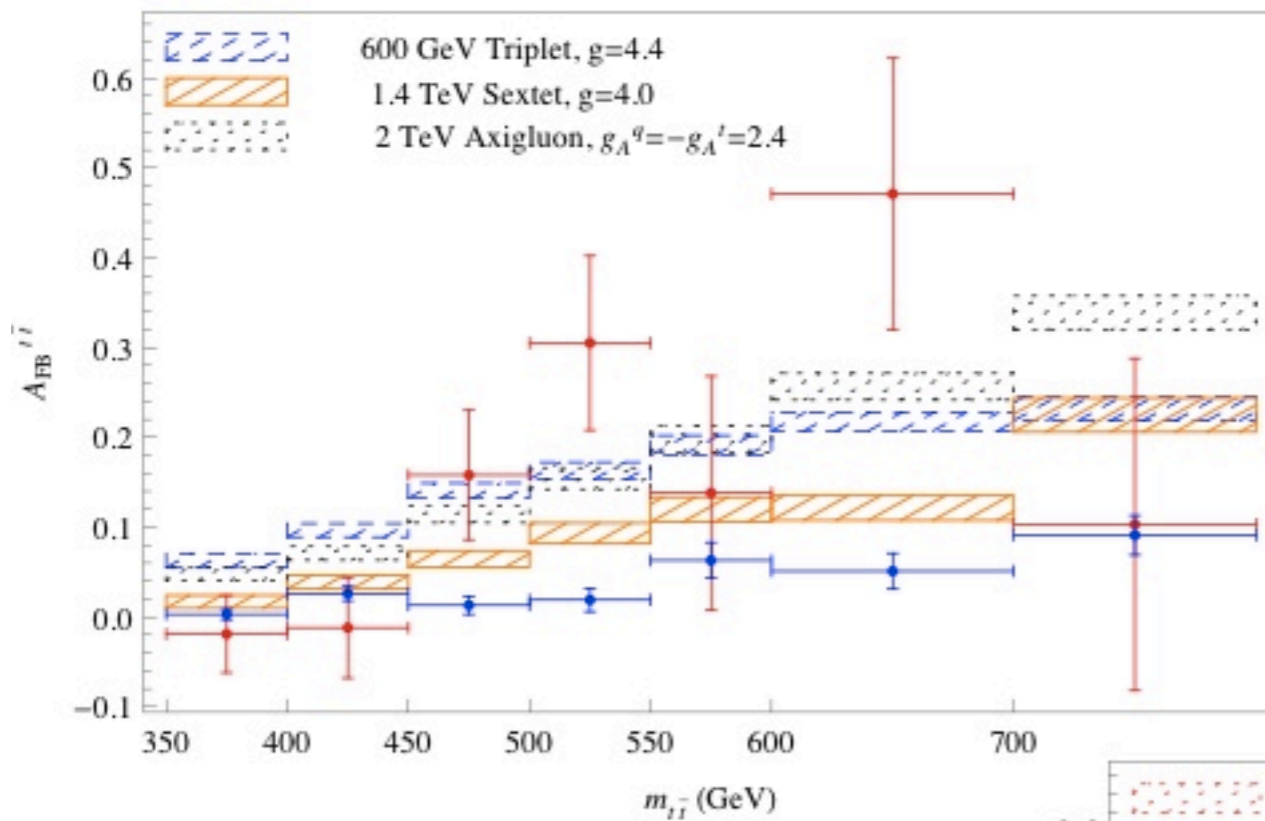
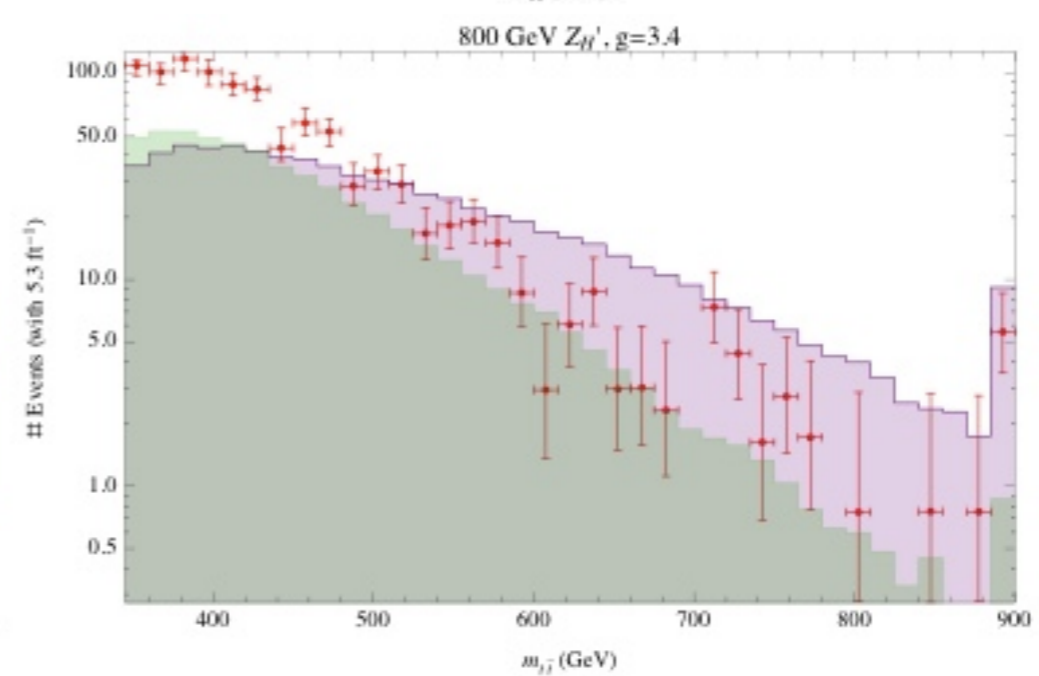# Jet multiplicity dependence of asymmetry (reconstructed events)
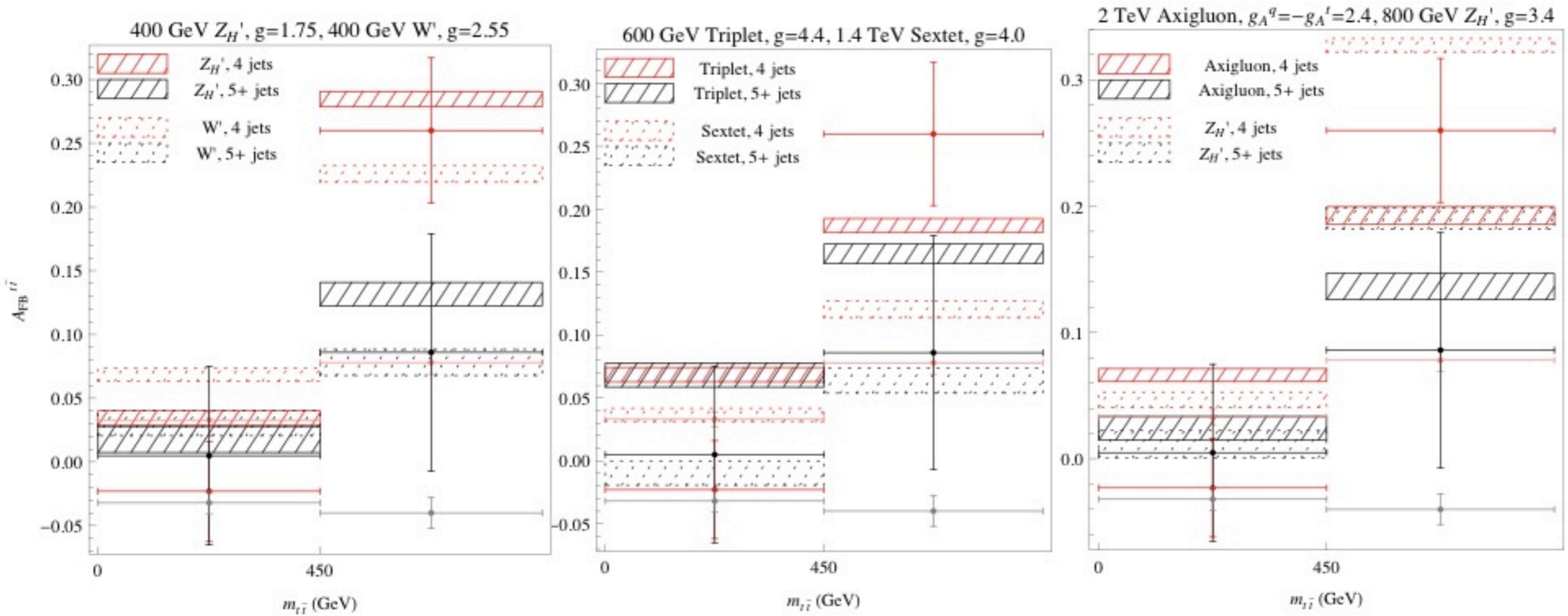
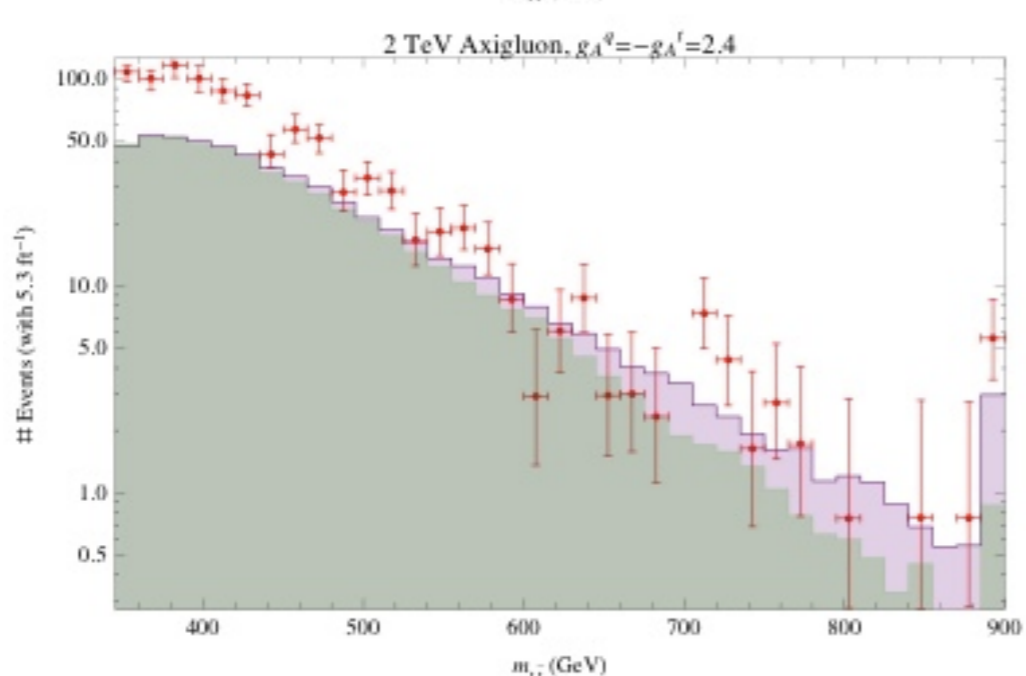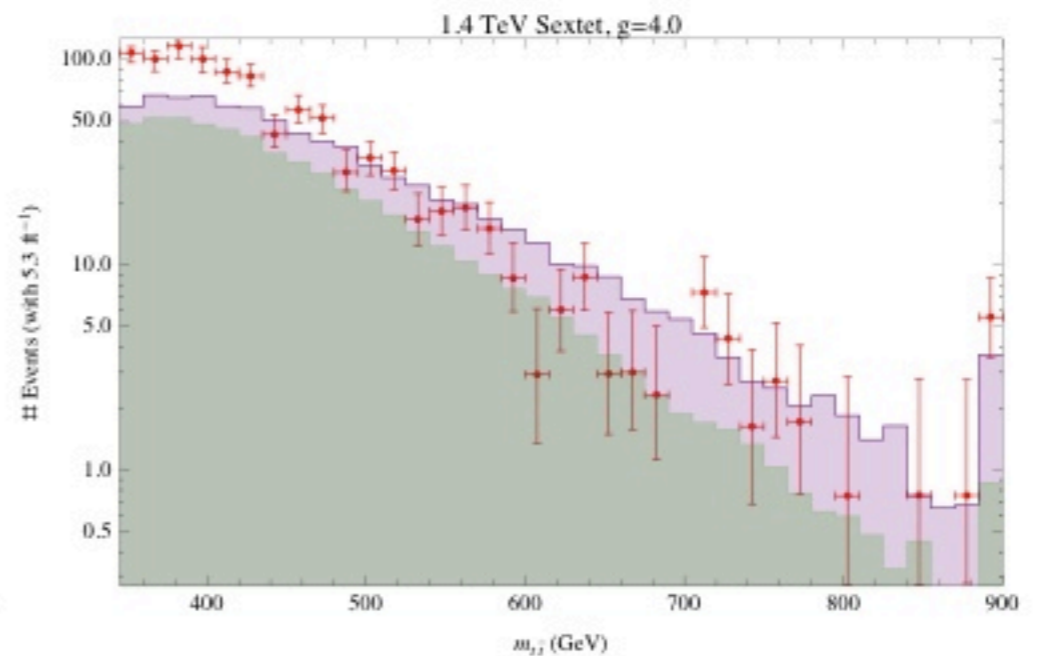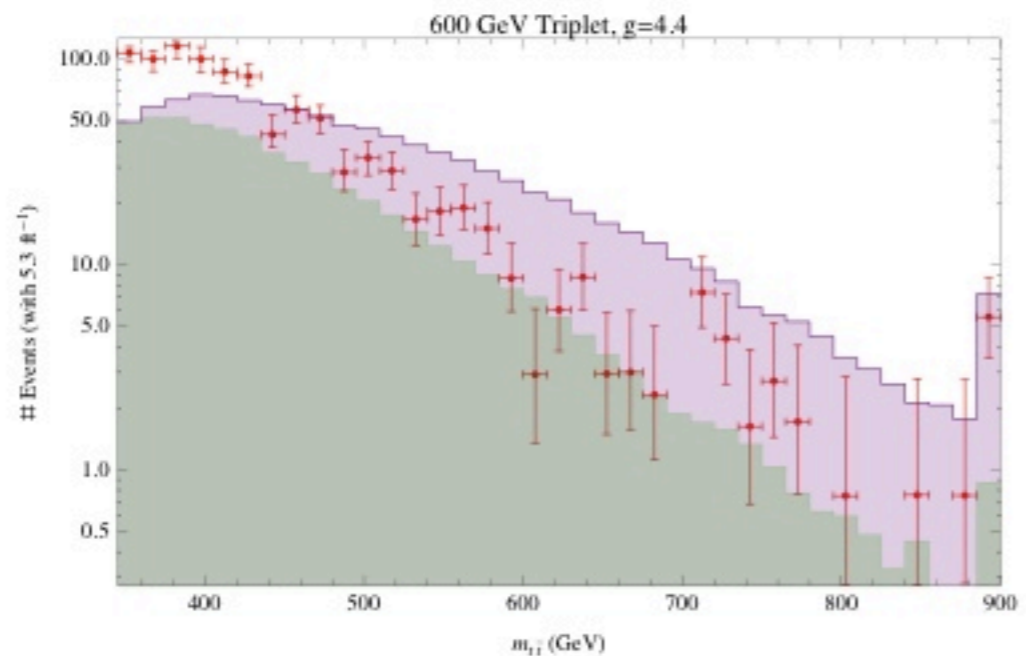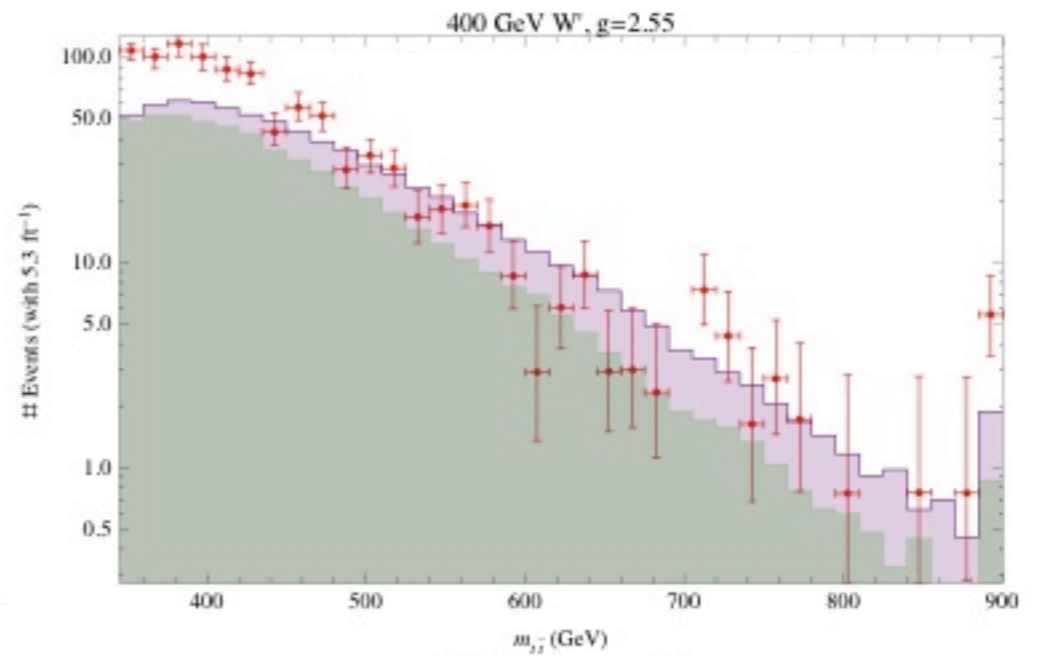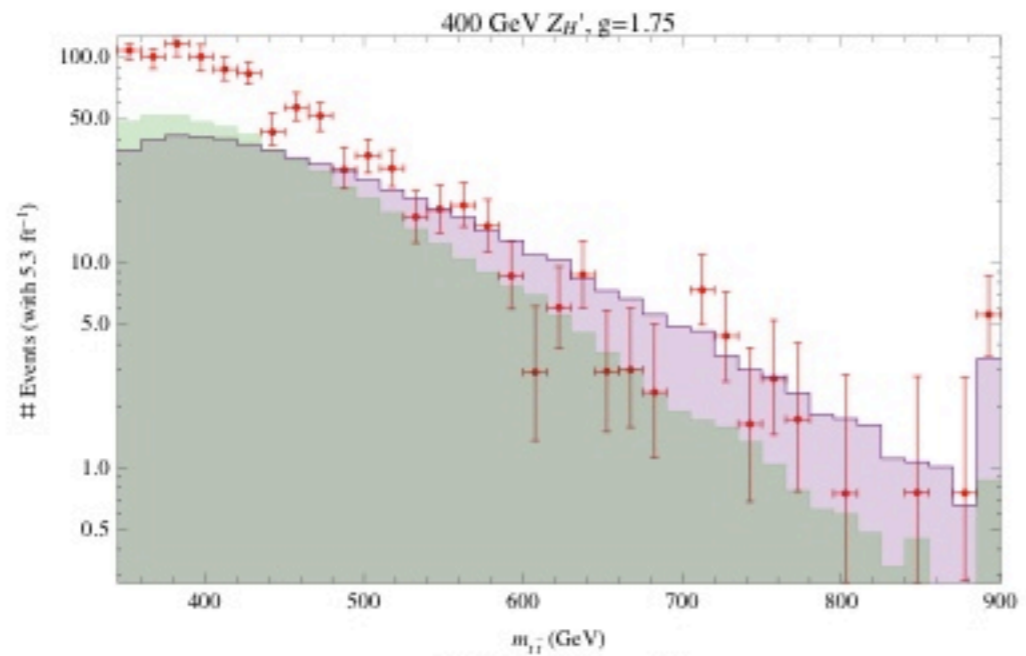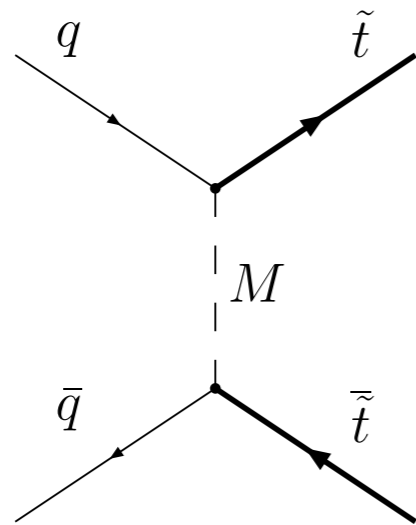# Mass-dependent asymmetry partitioned by lepton charge (reconstructed events)

Frame dependence of asymmetry (reconstructed events)

400 GeV Z_H', g=1.75, 400 GeV W', g=2.55

600 GeV Triplet, g=4.4, 1.4 TeV Sextet, g=4.0

2 TeV Axigluon, $g_A^q = -g_A^t = 2.4$, 800 GeV Z_H', g=3.4

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400 GeV Z_H', g=1.75

400 GeV W', g=2.55

600 GeV Triplet, g=4.4

1.4 TeV Sextet, g=4.0

2 TeV Axigluon, $g_A^q = -g_A^t = 2.4$

800 GeV Z_H', g=3.4
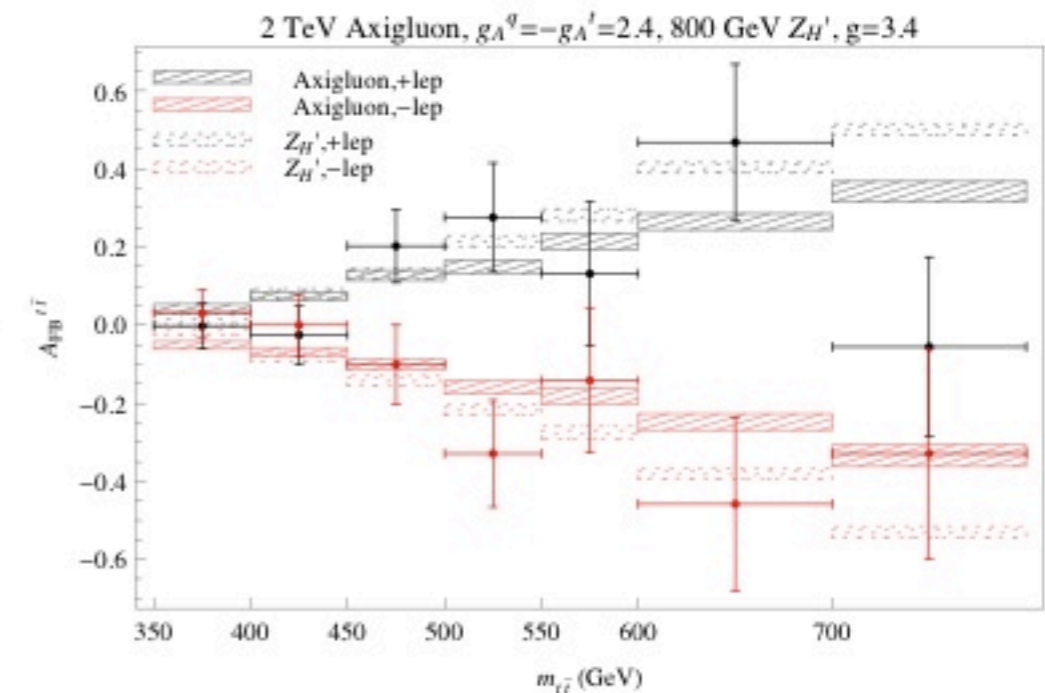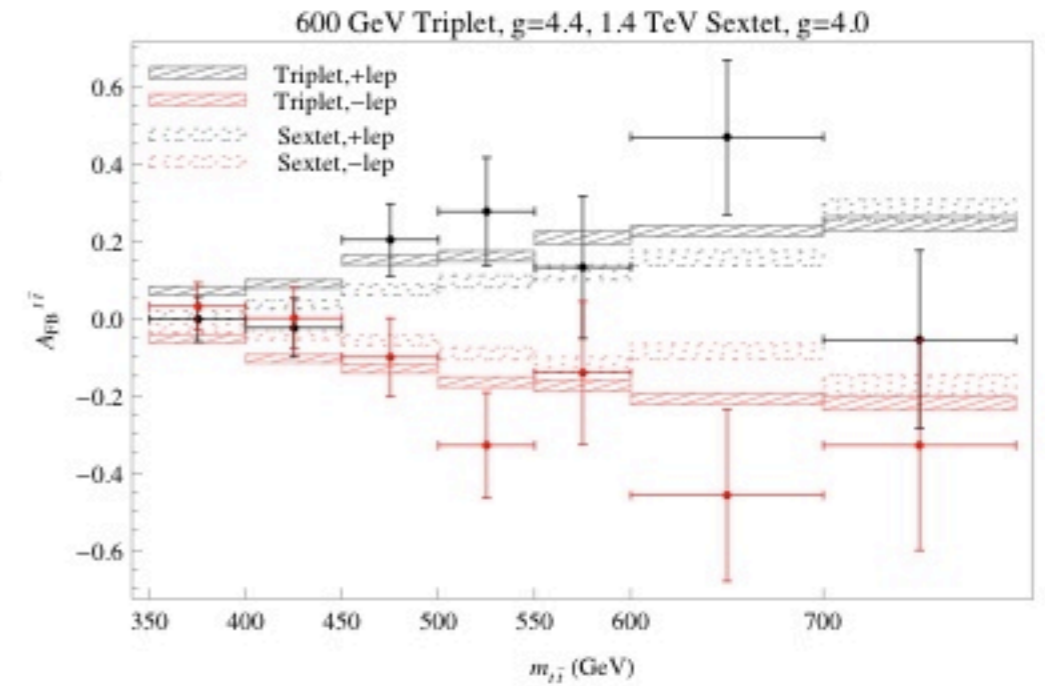
If: $(M: \text{top flavor-carrying mediator})$

then there necessarily exists:

(colored states only)
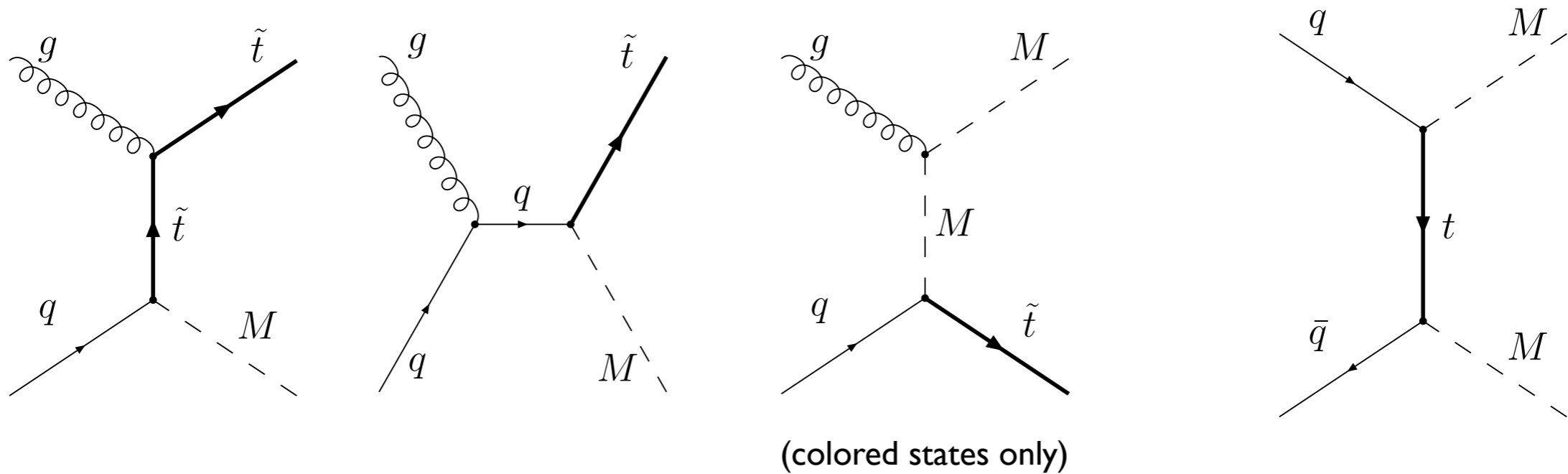
Leads to:

$\overline{t}j$ resonance in $t\overline{t}j$ events (Z', W')
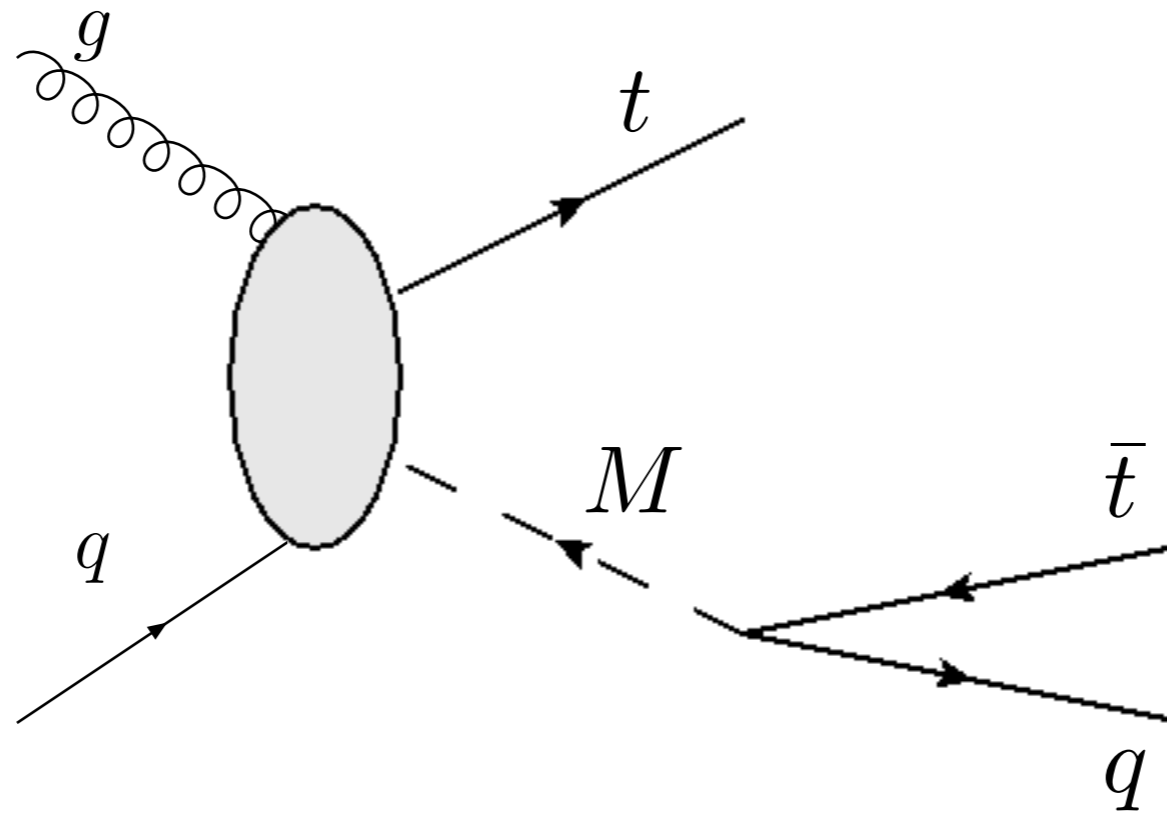
tj resonance in $t\overline{t}j$ events (triplet, sextet)

LHC reach from tj resonance [arXiv:1102.0018]

Legend:
- $5\,\sigma,\,1\,\text{fb}^{-1}$ (red, dotted)
- $3\,\sigma,\,1\,\text{fb}^{-1}$ (blue, solid)
- $5\,\sigma,\,10\,\text{fb}^{-1}$ (orange, dashed)
- $3\,\sigma,\,10\,\text{fb}^{-1}$ (purple, dash-dotted)

$g_R = 1.2$

$g_R = 0.8$

$g_R = 0.4$

Y-axis: $\sigma \times \text{BR}(\bar{t}j)$ (pb)

X-axis: $m_{\bar{t}j}$ (GeV)