A_{FB} AND LIGHT PHYSICS

(A MINI REVIEW)

Jure Zupan
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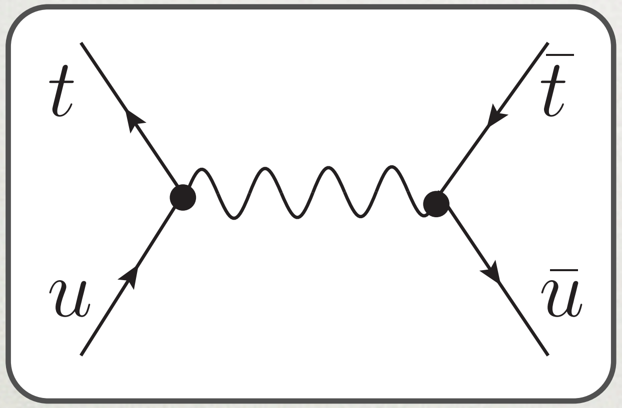
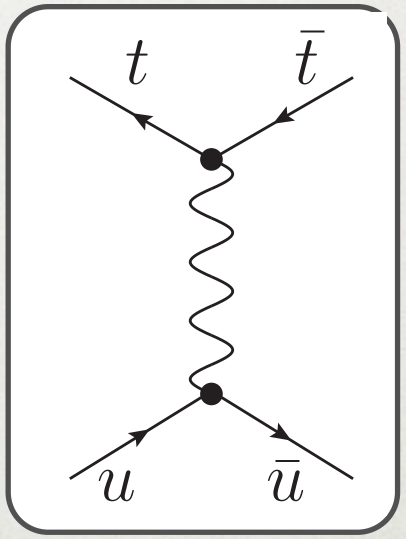
partially based on work with Grinstein, Kagan, Trott, (1102.3374, +unpublished)

THE SCOPE

- Working hypothesis: A_{FB} is due to New Physics
  - since the effects are large ⇒ tree level
  - *t*-channel? *s*-channel?





- Here: I review models where *t*-channel is important
  - "light NP" ~ O(300-500 GeV)

NONTRIVIAL

- Models have to be nontrivial
  - no significant effect in $d\sigma/dM_{tt}$
    see also talks by T. Schwarz, A. Harel, B. Pecjak
  - constraints from dijets
    see a talk by A. Kagan this afternoon
  - same sign tops
  - single top production
  - flavor constraints

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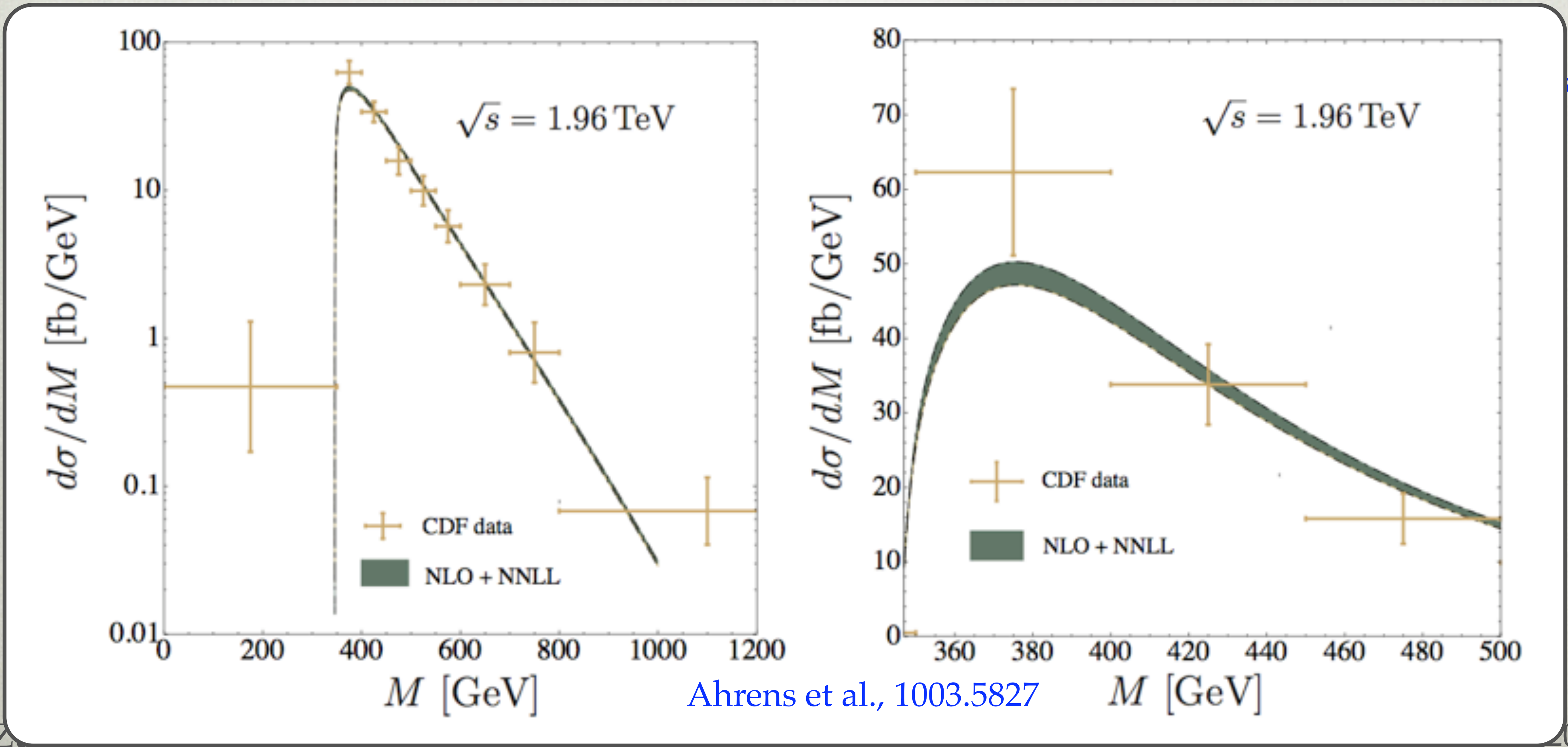
afternoon



Ahrens et al., 1003.5827

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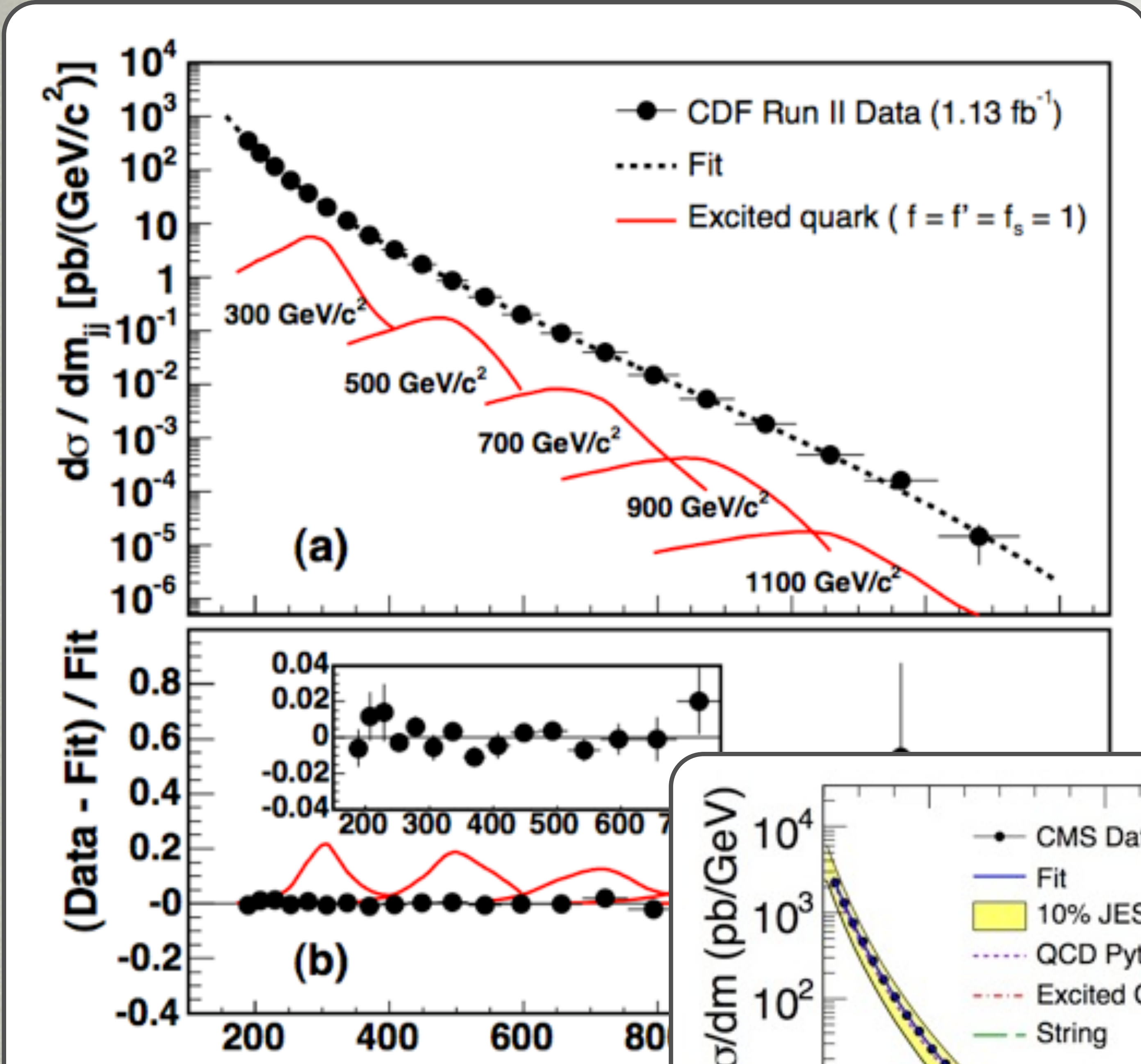
...RIVIAL

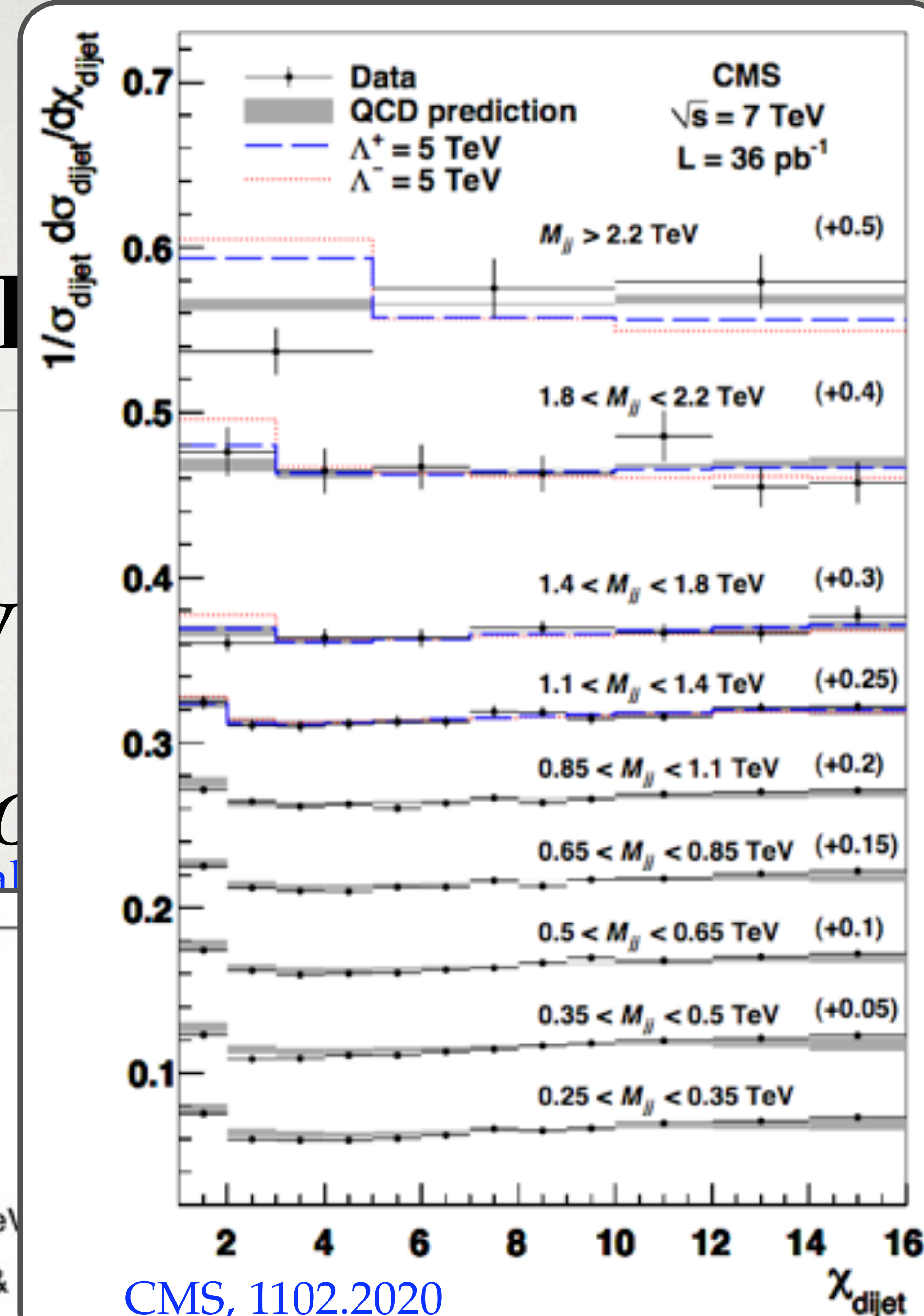
nontriv...

...ect in $d\sigma$...

see al...

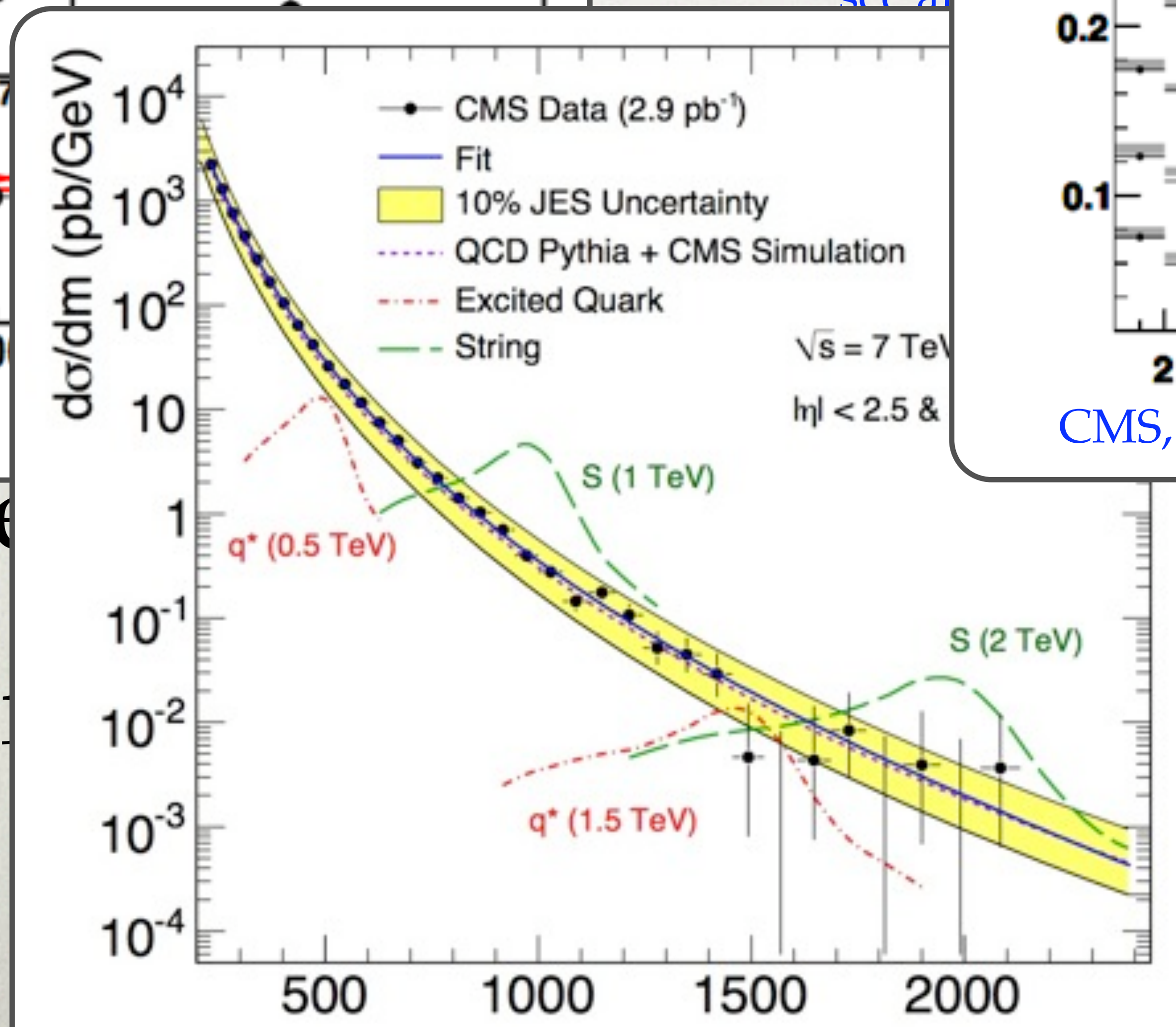


CDF, 0812.4036



CMS, 1102.2020

- single...
- flavo...



CMS 1010.0203

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NEW PHYSICS?

- First question: does it have to interfere with SM?

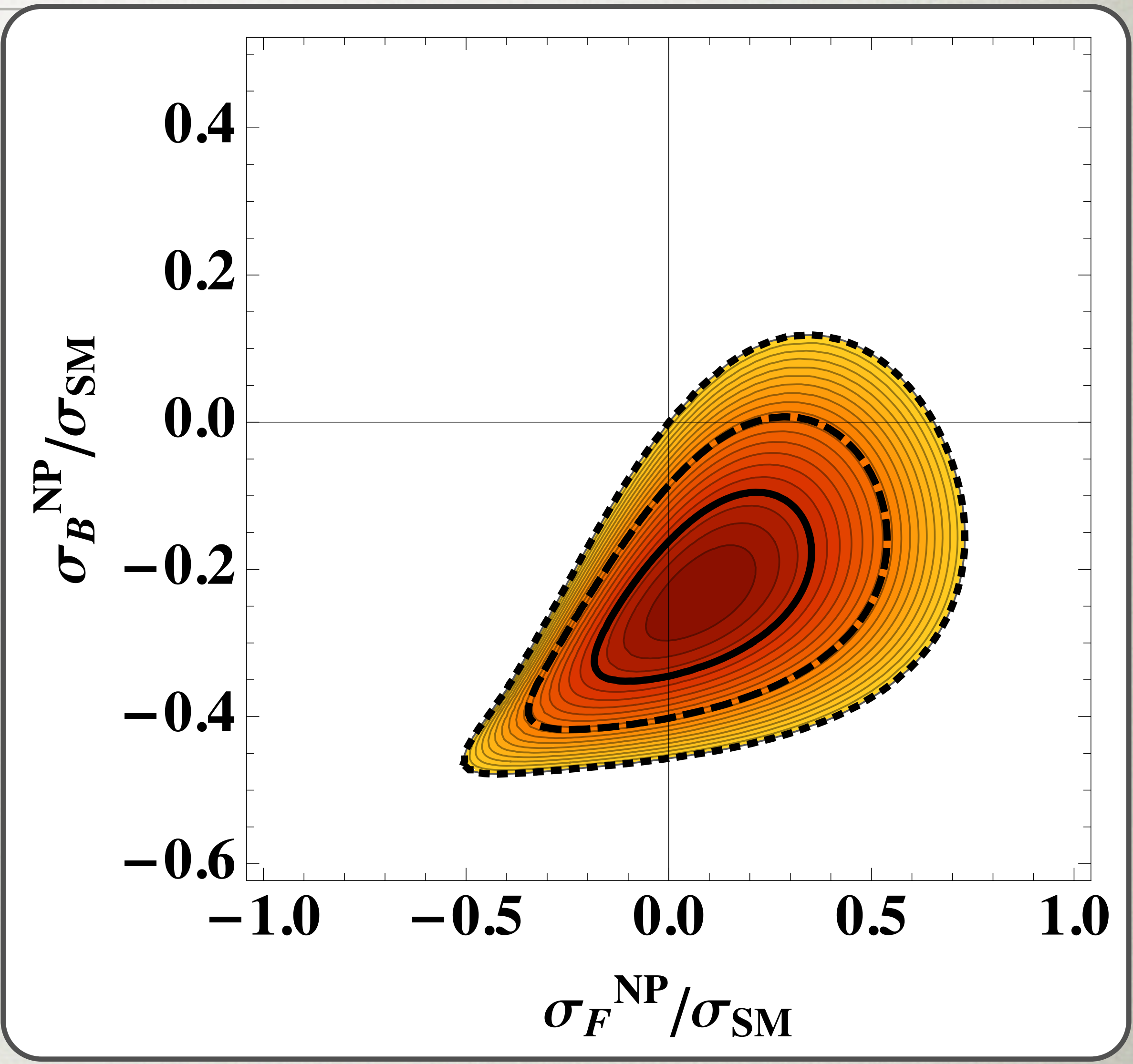
$$A_{FB}^{t\bar{t}} = \frac{\sigma_F^{SM} - \sigma_B^{SM} + \sigma_F^{NP} - \sigma_B^{NP}}{\sigma_F^{SM} + \sigma_B^{SM} + \sigma_F^{NP} + \sigma_B^{NP}}$$

- cross section agrees with the SM

$$\sigma_{exp}^{t\bar{t}}(M_{t\bar{t}} > 450\text{GeV}) = 1.9 \pm 0.5 \text{ pb}$$
$$\sigma^{SM}(M_{t\bar{t}} > 450\text{GeV}) = 1.78 \pm 0.14 \text{ pb}$$

MODEL INDEP. FIT

- σ_B is large and negative
  - it has to interfere with the SM
- if s-channel resonance:
  - to interfere with one-gluon exchange has to be color-octet
  - cannot be a scalar ⇒ "axigluon"



THREE SETS OF "T-CHANNEL"MODELS

- "*t*-channel" models
  - large flavor violation
  - flavor conserving
  - not exactly ttbar, but ttbar+X (so no inteference)

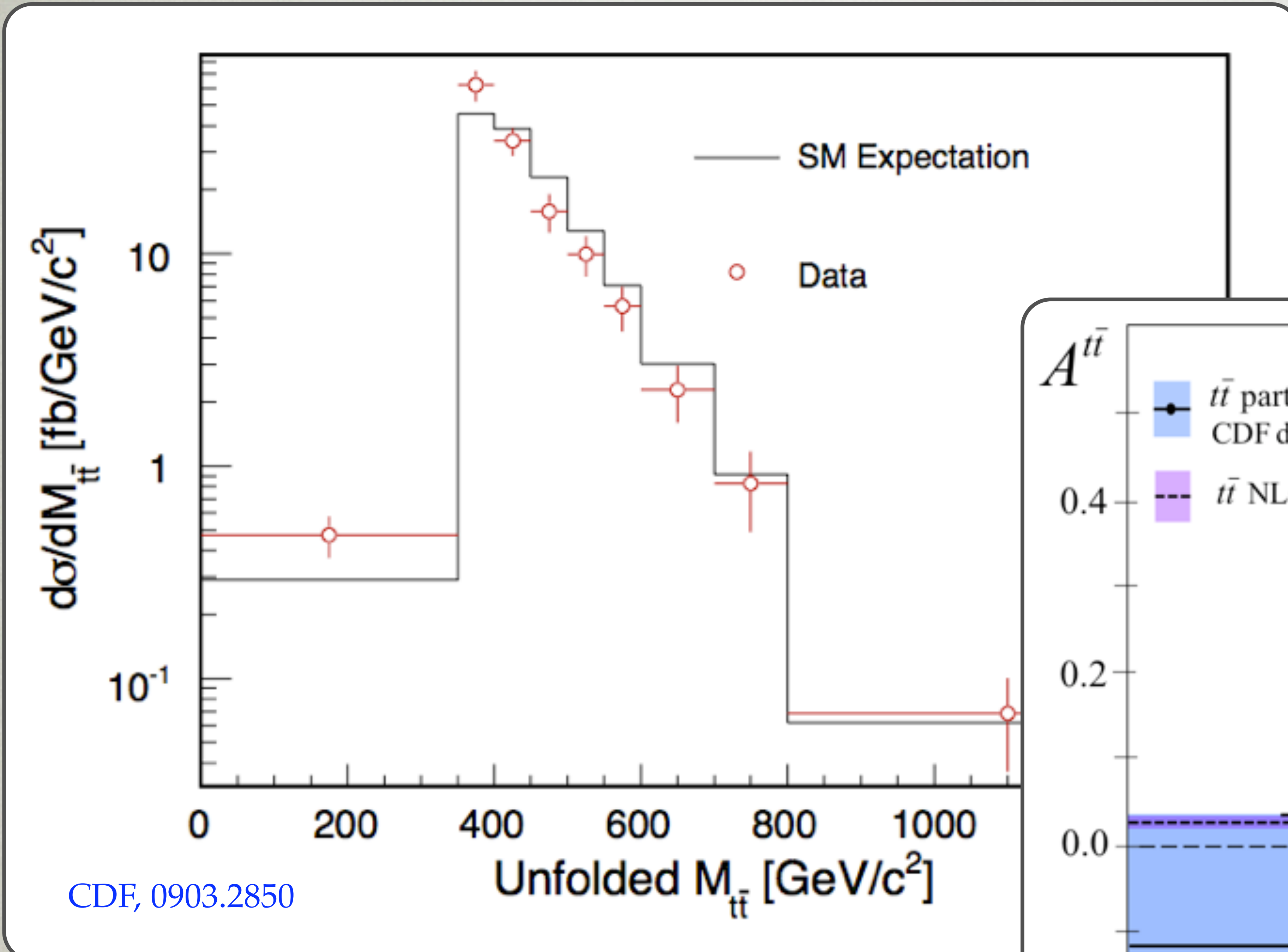
for heavy modes and A_{FB} see a talk by O. Gedalia

COMPARING WITH DATA

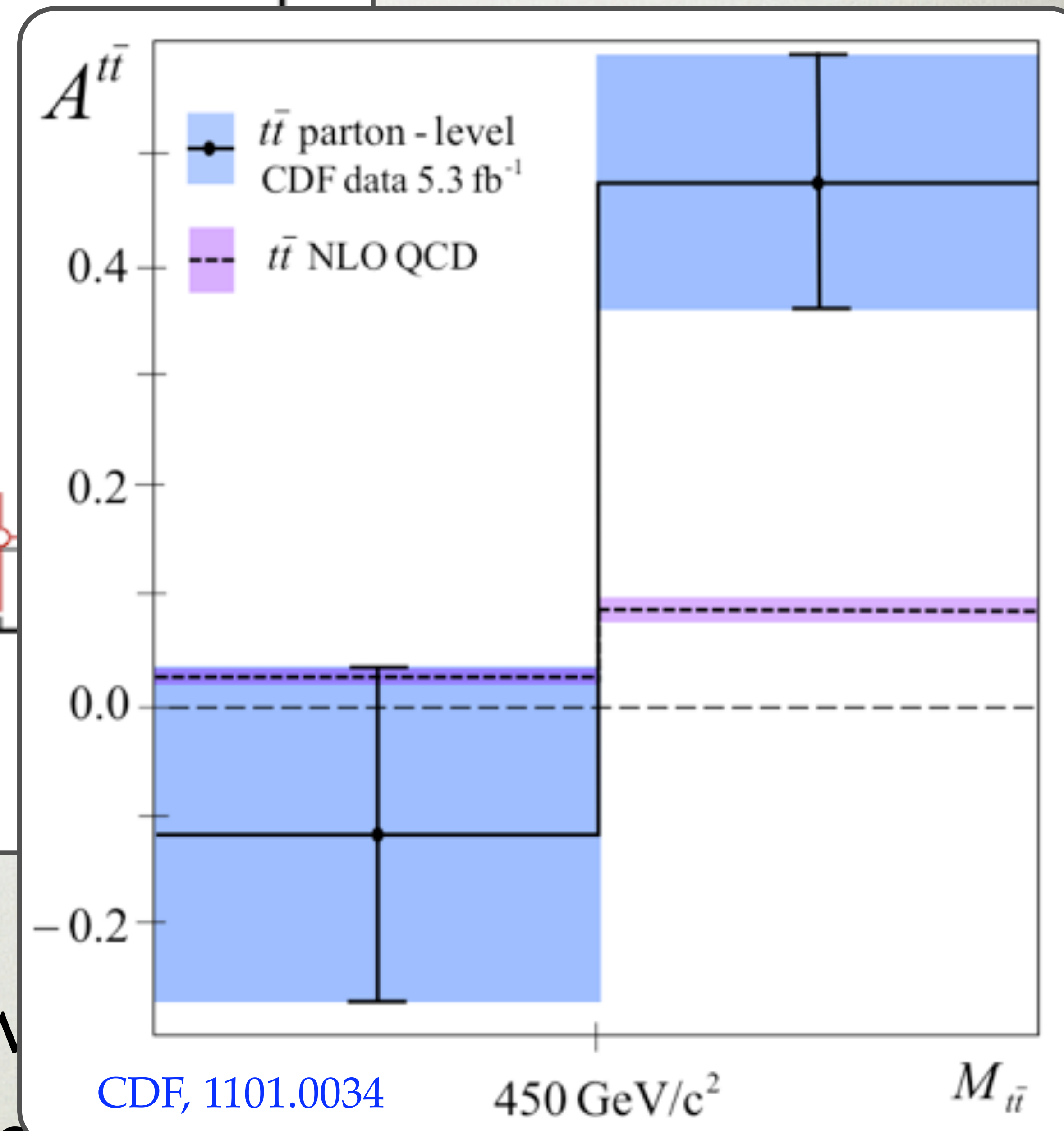
- CDF quotes also "deconvoluted" A_{FB} and $d\sigma/dm_{tt}$
- maybe easiest to compare with the NP models
- but deconvolution done assuming SM ttbar production
- for very forward ttbar production this may be a problem
    - especially for $d\sigma/dm_{tt}$ where deconvolution using η integrated efficiencies

Gresham, Kim, Zurek, 1103.3501

DATA



CDF, 0903.2850



CDF, 1101.0034

problem

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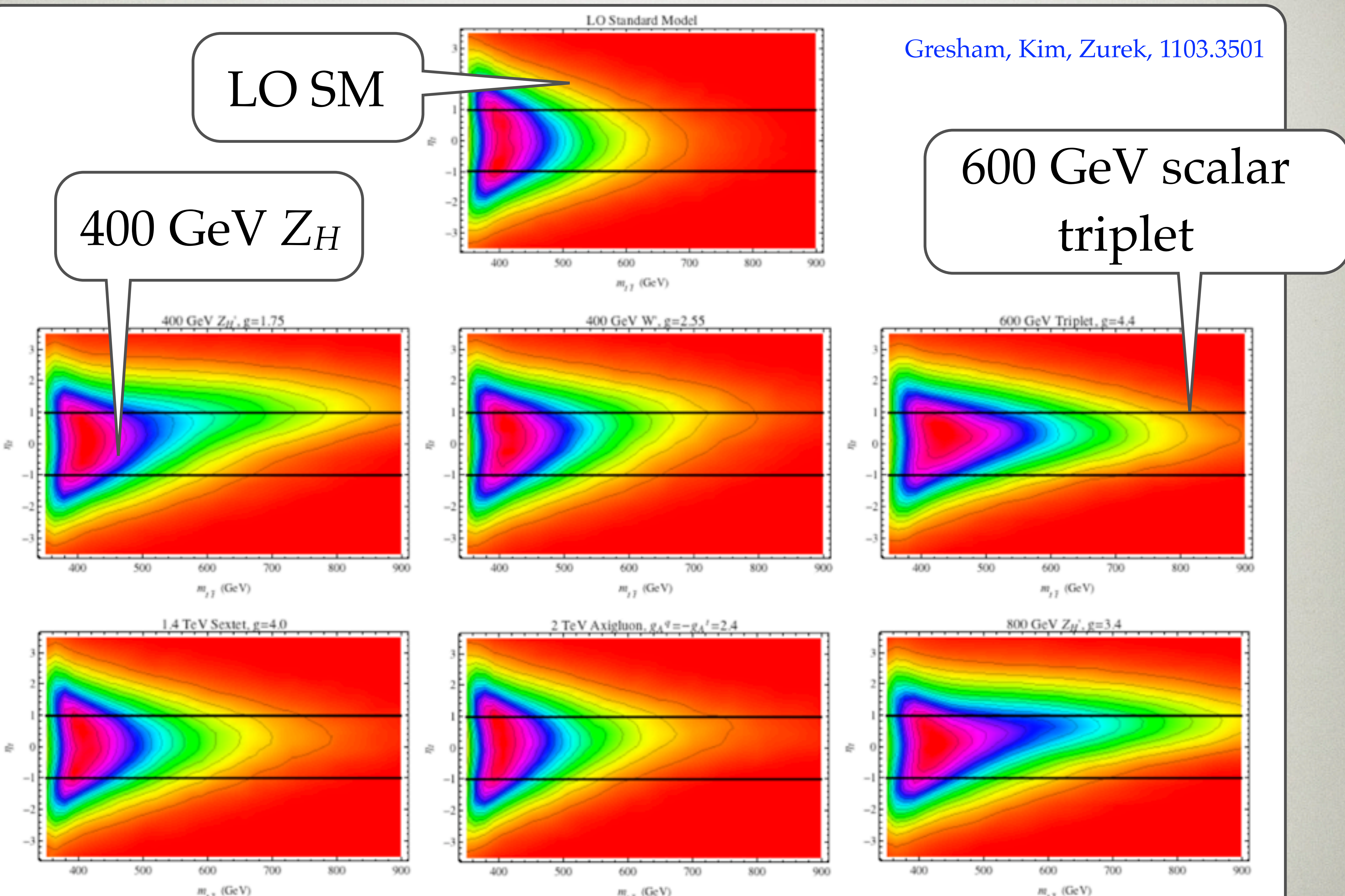
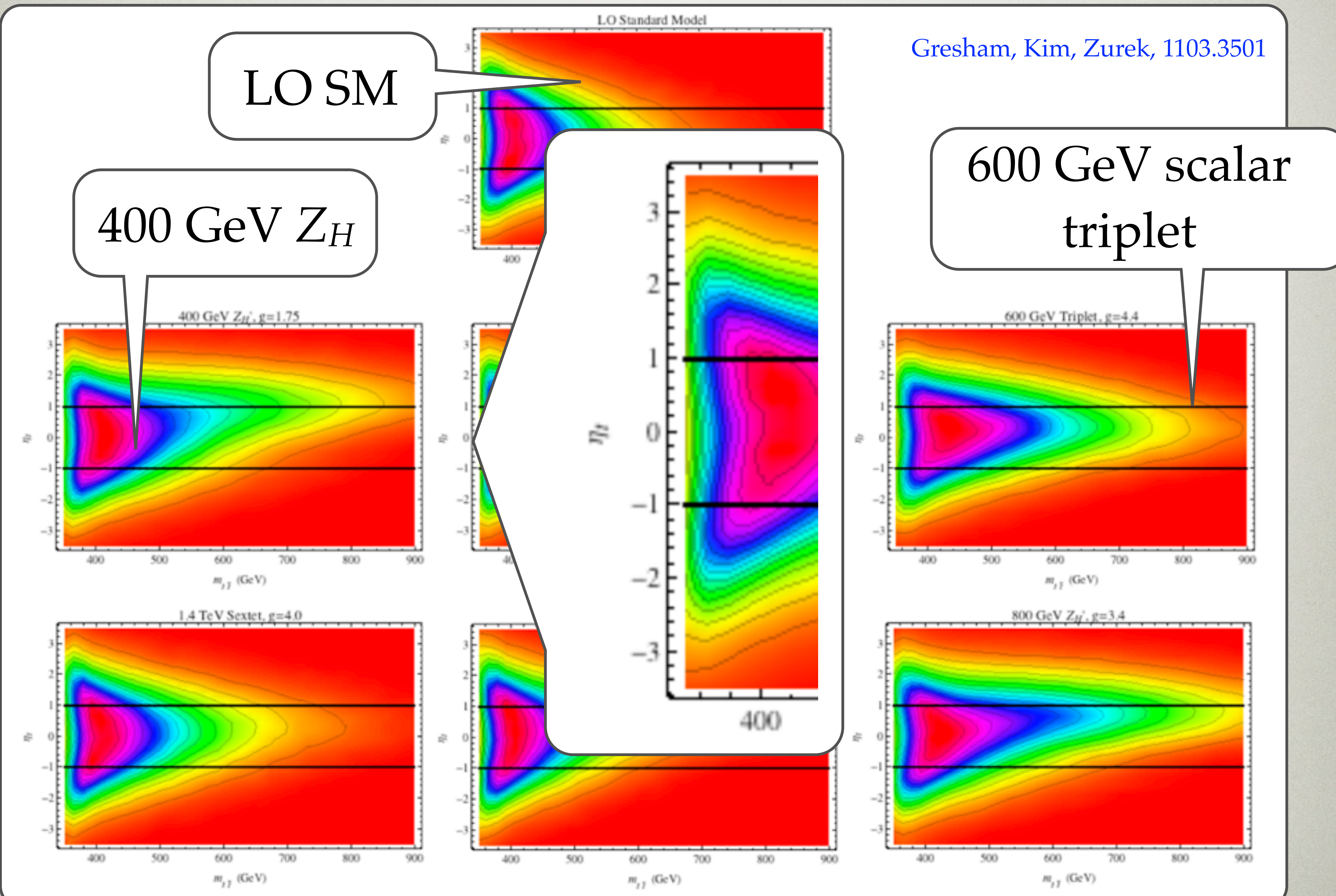




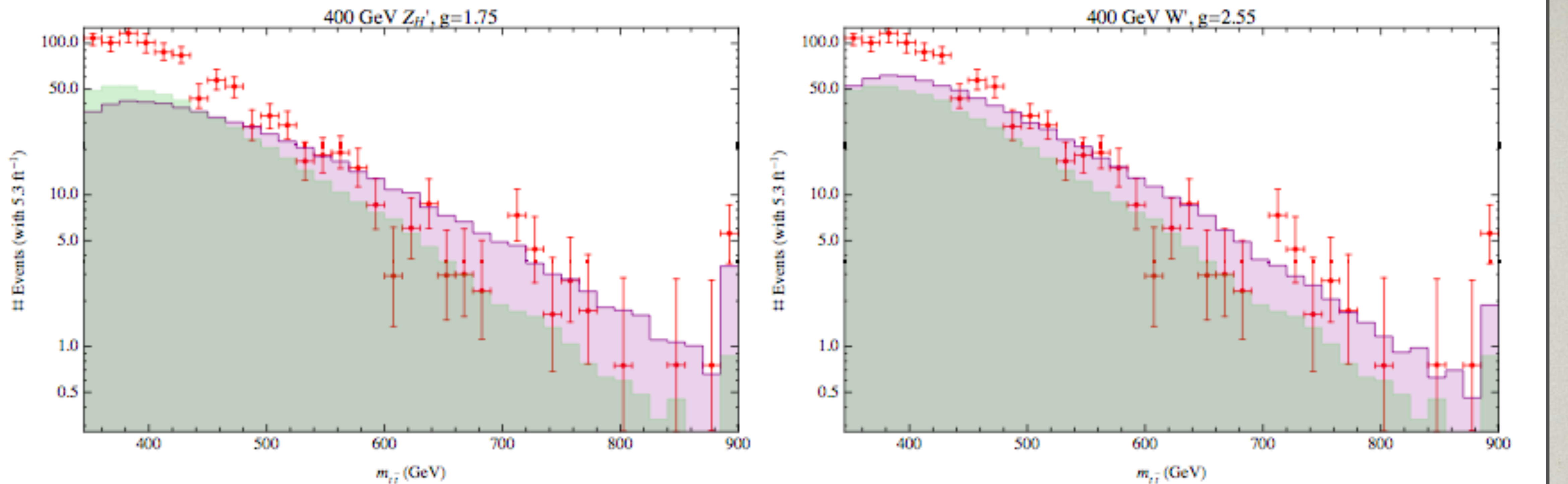
Gresham, Kim, Zurek, 1103.3501
LO SM
400 GeV Z_H
600 GeV scalar triplet
LO Standard Model
400 GeV $Z_{H'}$, g=1.75
600 GeV Triplet, g=4.4
1.4 TeV Sextet, g=4.0
800 GeV $Z_{H'}$, g=3.4
η_t
$m_{t\bar{t}}$ (GeV)

SEVERAL COMMENTS

- effect most important for light t-channel
- expected bigger for vectors than scalar
- Gresham et al. compare with cross section in 1101.0034 not in 0903.2850
    - implicitly cuts(0903.2850)=cuts(1101.0034)
- have performed a new analysis

Grinstein, Kagan, Trott, JZ, in preparation

    - approach that is useful for "`Mathematica` based " studies
    - easier to scan over many models
    - `Madgraph+Pythia+PGS need to be` run only ones
    - exact in the limit of small bins and no spill-over



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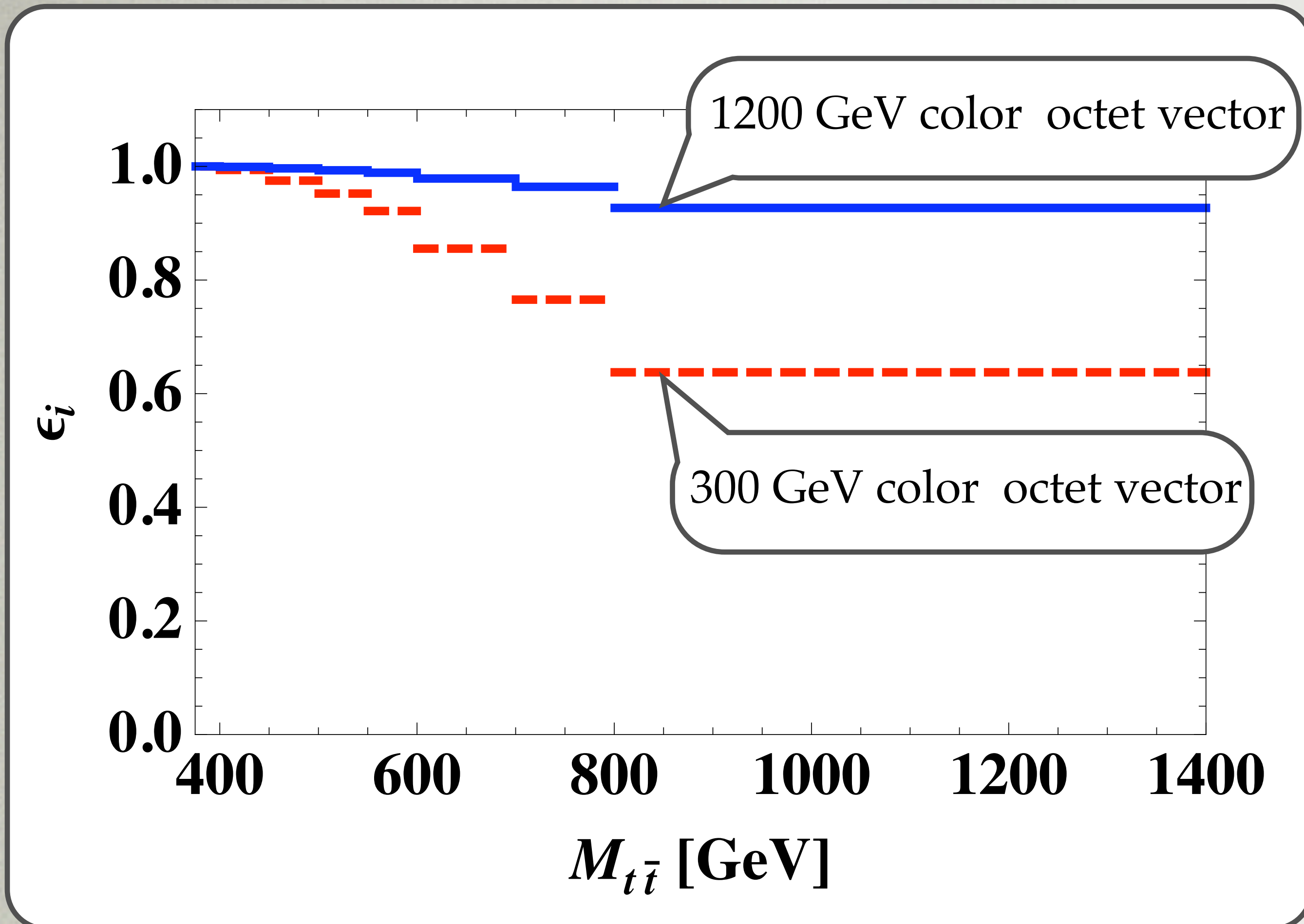
DETAILS

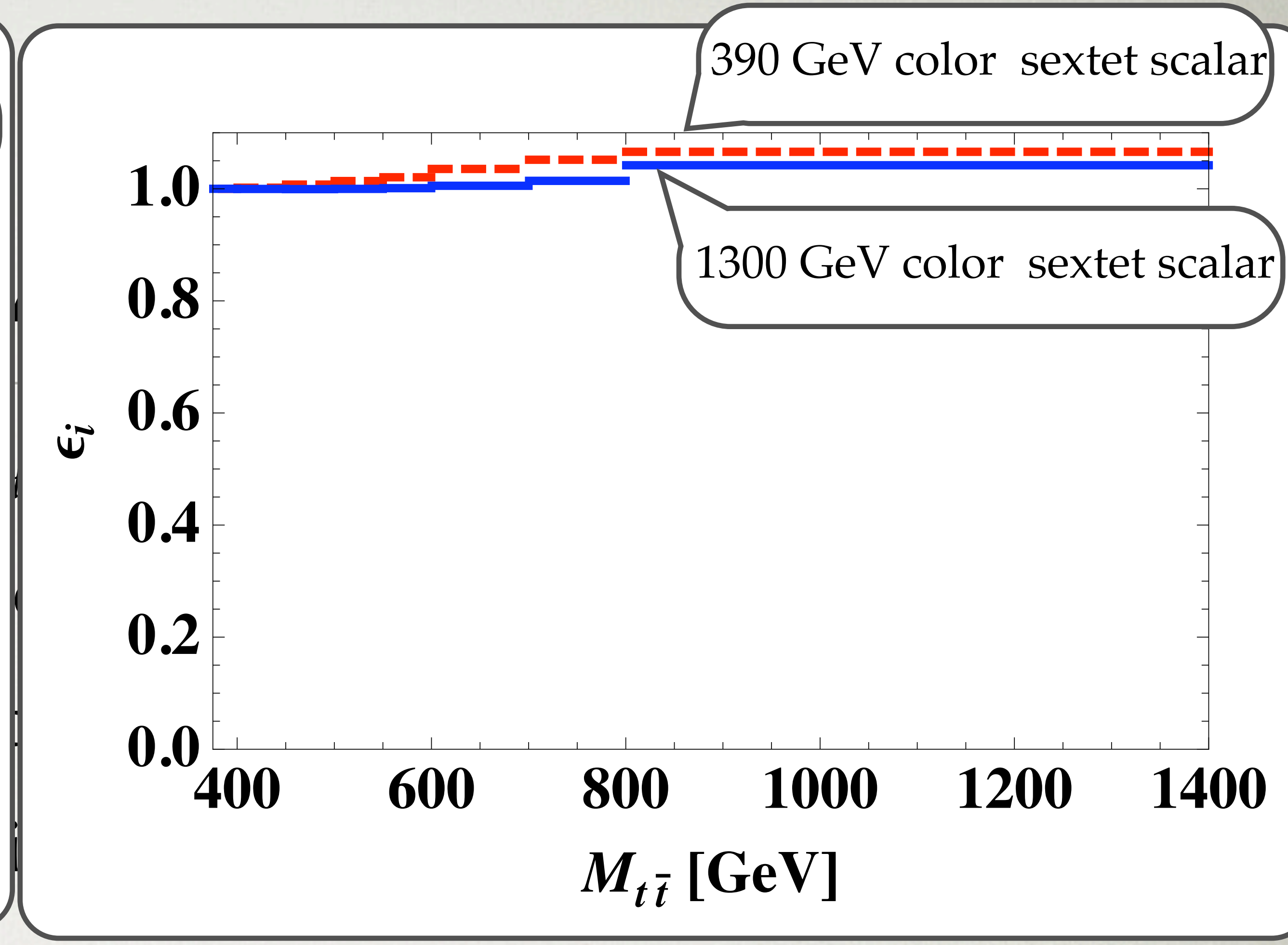
- make a 2D set of bins in m_{tt} and Δy
- use `Madgraph` to generate SM ttbar partonic cross section
  - but restricted to a particular bin in m_{tt} and Δy
  - trick: implement cuts directly in `Subprocesses/cuts.f`
- run through `Pythia+PGS` to obtain efficiencies $\varkappa_{ij}$ (i- bin in m_{tt}, j-bin in Δy)
- the "correction factor" to be used when comparing with CDF dsigma/dmtt measurement is

$$\epsilon_i^{\rm SM,NP} = \frac{\sum_j \sigma_{ij}^{\rm SM,NP} \kappa_{ij}}{\sum_j \sigma_{ij}^{\rm SM,NP}}$$

$$\left(\frac{d\sigma^{\rm NP}}{dm_{t\bar t}}\right)_i^{CDF} = \epsilon_i \times \left(\frac{d\sigma^{\rm NP}}{dm_{t\bar t}}\right)_i$$

$$\epsilon_i = \frac{\epsilon_i^{\rm NP}}{\epsilon_i^{\rm SM}}$$





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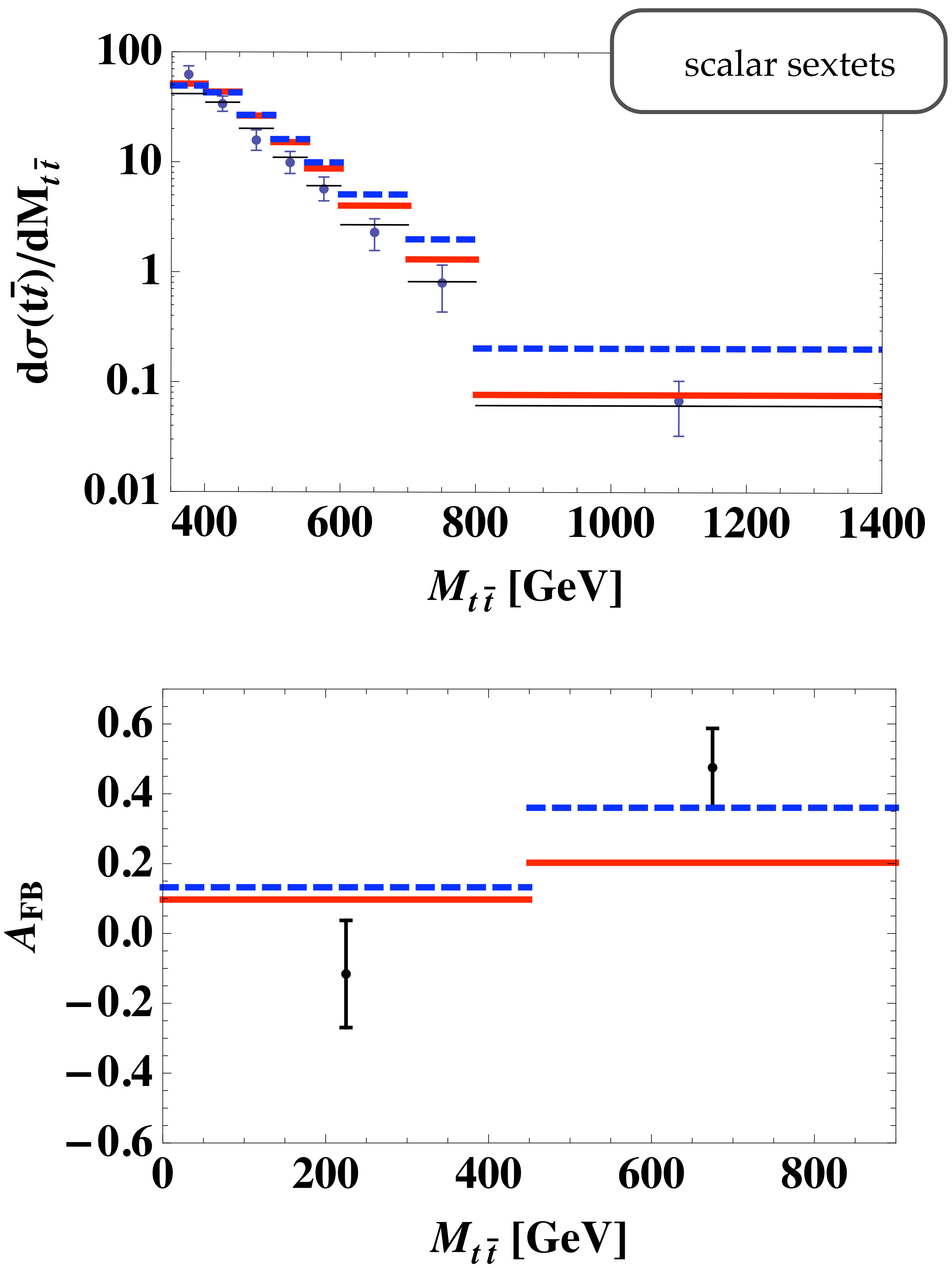
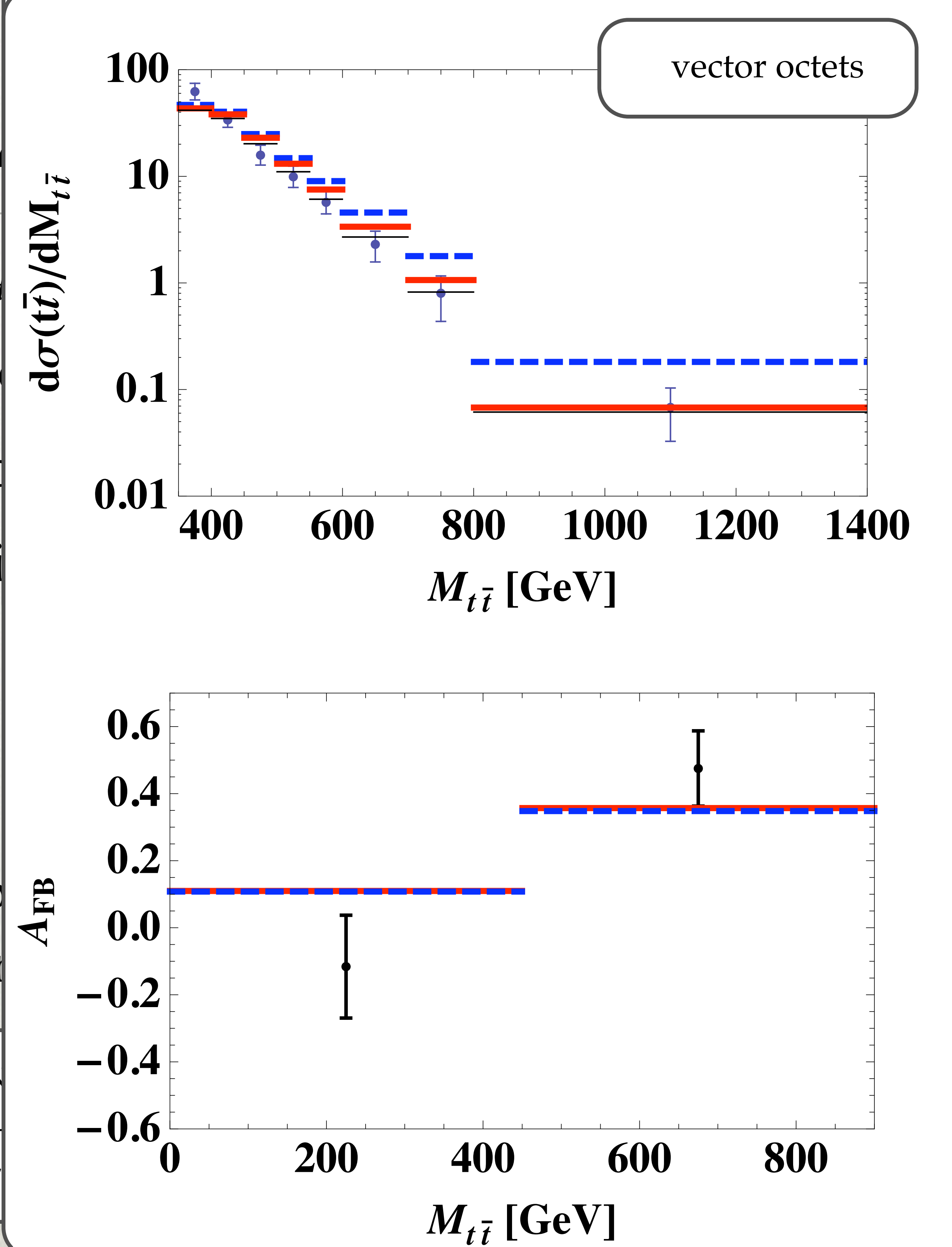
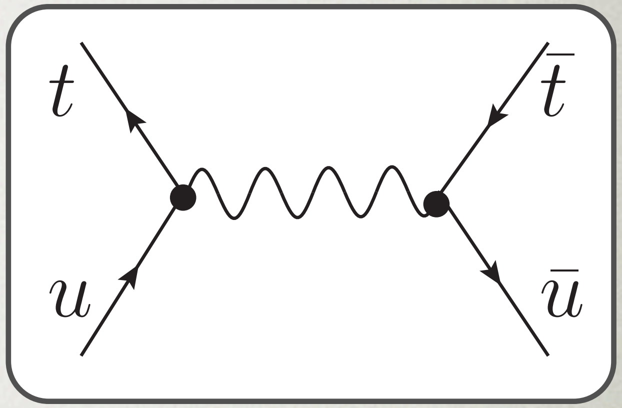
390 GeV color sextet scalar





THE MODELS

LARGE FLAVOR VIOLATION



- large flavor violation: e.g. only *t*-*u* coupling
  S. Jung, A. Pierce, J. D. Wells 1103.4835
- example: non-Abelian model of Jung et al.
  - t_R and u_R are in a doublet of $SU(2)_X$
  - W′ and Z′ gauge bosons of $SU(2)_X$ (EM neutral)
  - this avoids same sign *tt* constraints that kill the Abelian model
    S. Jung, H. Murayama, A. Pierce, J. D. Wells, 0907.4112
  - if $SU(2)_X$ broken by a scalar doublet ⇒ "$SU(2)_X$ custodial symmetry" ⇒ $m_{W'}=m_{Z'}$
  - custodial symm. needs to be broken for viable phenomenology

NON-CUSTODIAL LAGRANGIAN

$$\mathcal{L} = \frac{g_X}{\sqrt{2}} W'^{-}_{\mu} \left\{ \bar{t}_R \gamma^\mu t_R(-cs) + \bar{u}_R \gamma^\mu u_R(cs) + \bar{t}_R \gamma^\mu u_R(c^2) + \bar{u}_R \gamma^\mu t_R(-s^2) \right\}$$
$$+ \frac{g_X}{\sqrt{2}} W'^{+}_{\mu} \left\{ \bar{t}_R \gamma^\mu t_R(-cs) + \bar{u}_R \gamma^\mu u_R(cs) + \bar{t}_R \gamma^\mu u_R(-s^2) + \bar{u}_R \gamma^\mu t_R(c^2) \right\}$$
$$+ \frac{g_X}{2} Z'_{\mu} \left\{ \bar{t}_R \gamma^\mu t_R(c^2 - s^2) + \bar{u}_R \gamma^\mu u_R(s^2 - c^2) + \bar{t}_R \gamma^\mu u_R(2cs) + \bar{u}_R \gamma^\mu t_R(2cs) \right\}.$$

$c = \cos\theta$ and $s = \sin\theta$

- $\theta \neq 0 \Rightarrow t_R$ and u_R numbers are broken
- $\cos\theta$ needs to be close to one so that large A_{FB} from *u-t-W′* and small *u-u-W′* ($0.92 < \cos\theta$)
- but dijets require $\cos\theta < 1$ so that reduced *u-u-Z′* coupling
- their prefered choice is

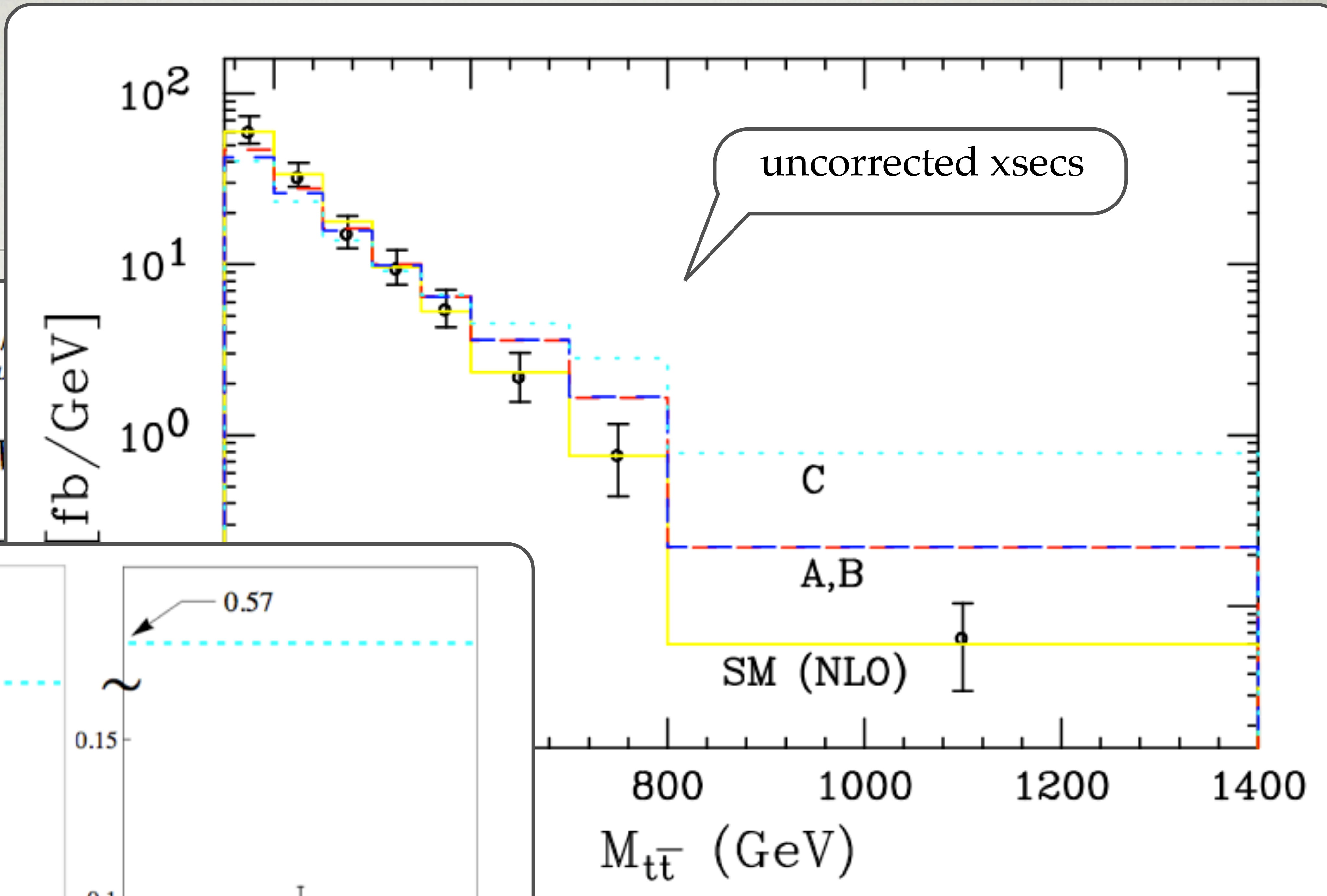
	$M_{W'}$ (GeV)	$M_{Z'}$ (GeV)	α_X	$\cos\theta$
A:	200	280	0.060	0.95

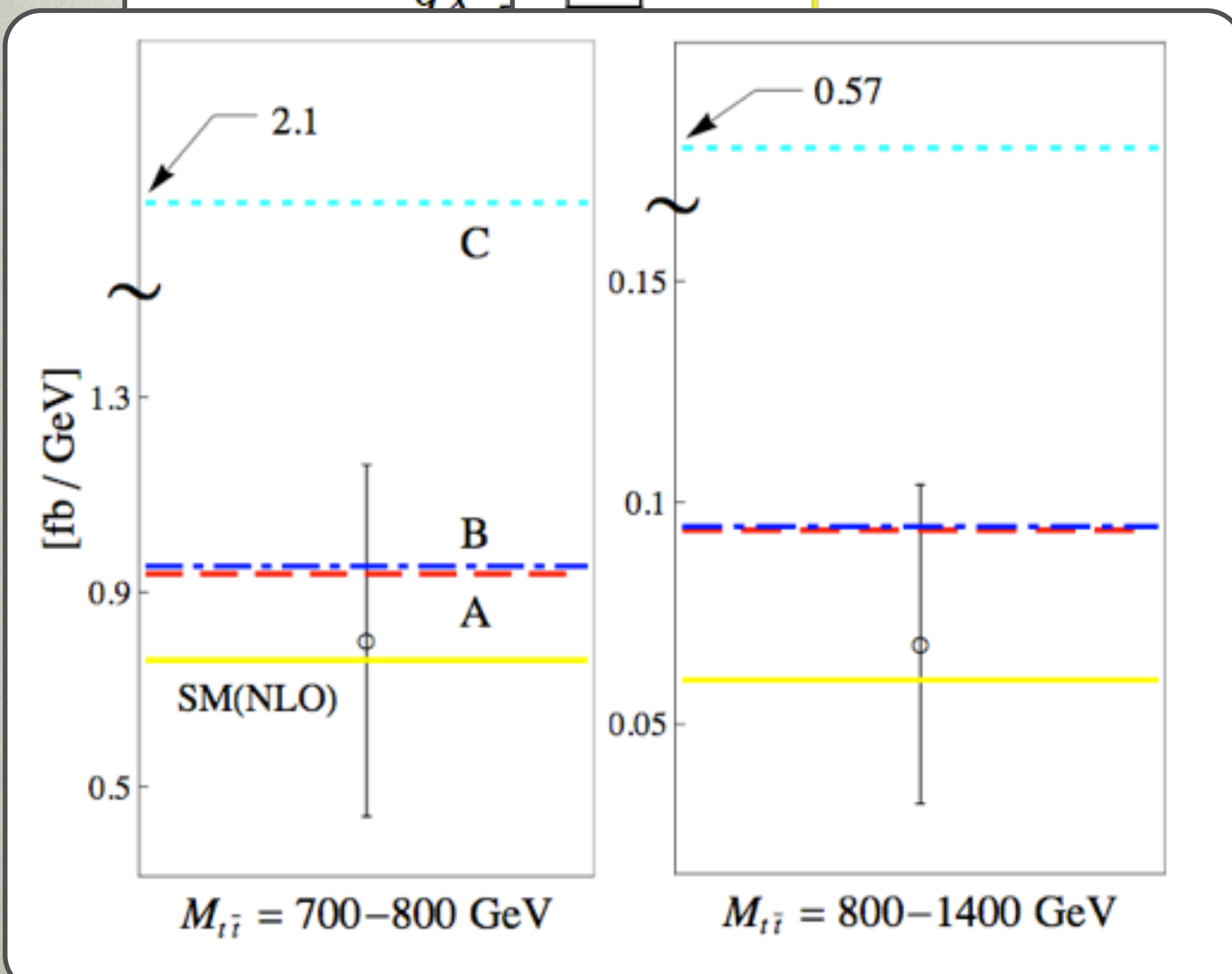
  - gives $A_{FB}(>450) = 0.22$ (0.30)

$\mathcal{L} = \frac{g_X}{\sqrt{2}} W'_\mu$ …

$+ \frac{g_X}{\sqrt{2}}$ …

g_X …





…t reduced *u*-*u*-Z' coupling

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FLAVOR STRUCTURE

S. Jung, A. Pierce, J. D. Wells 1103.4835
another example: Shelton, Zurek 1101.5392

- if there is an $SU(2)_X$ doublet with vev.
  - generates (only) top mass from dim 5 operator

$$\Delta\mathcal{L} \ni \frac{(\lambda'_u)_i}{M}(\bar{Q}_i \cdot h_{SM})(\phi_D \cdot q).$$

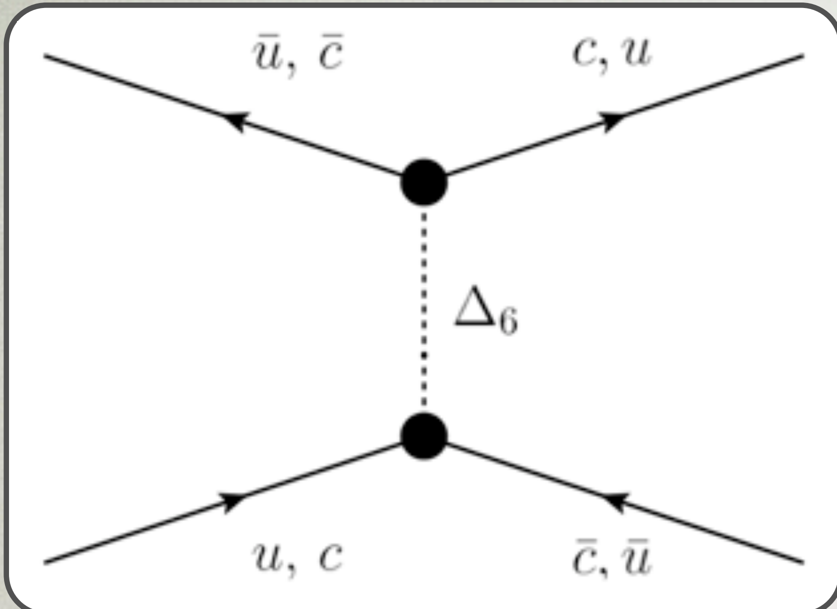
$$q = (t_R, u_R)$$

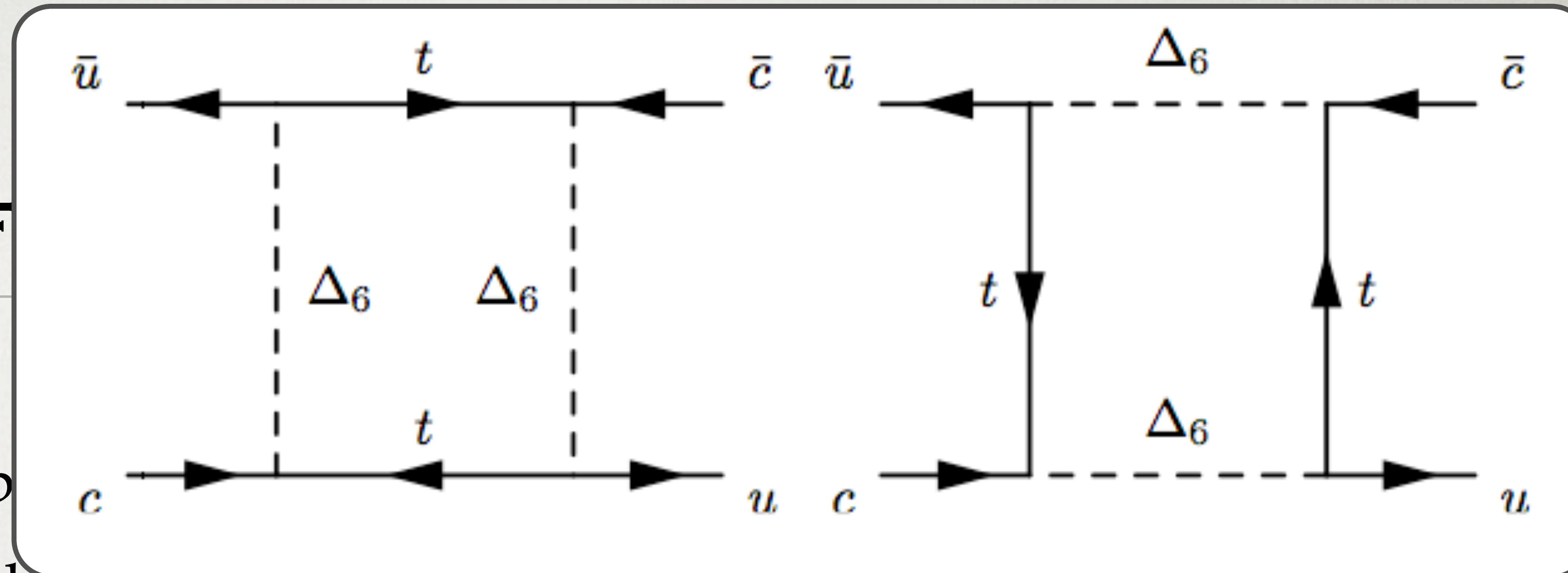
- unspecified in their paper, but potentially
  - charm quark a mass from dim 4 operator (SM yukawa)
  - u-quark mass from higher dim. ops.?
- vacuum alignment problem:
  - the charm quark direction needs to be aligned finely so that no u_R-c_R-W' or u_R-c_R-Z' couplings
  - the direction of scalars giving mass to W′-Z′ need to be aligned with top-quark mass direction to ~5% (note: these are necessarily different scalars)
- also extra states so that the $SU(2)_X$ is not anomalous

A_{FB} from GUTS

Dorsner, Fajfer, Kamenik, Kosnik, 0912.0972; 1007.2604

- non-SUSY SU(5) model
- 45-dim higgs rep. is split
  - two light scalars at TeV: Δ_6~(3,1,-4/3), Δ_1~(8,2,1/2)
  - these do not mediate proton decay at tree level
  - the remaining part of the multiplet heavy
- to have gauge coupl. unif.: similar split in 24-dim fermionic mutiplet
  - also gives neutrino masses through type I and III see-saw
- to have positive A_{FB} m(Δ_6)~300 GeV, m(Δ_1)~1 TeV
  - Δ_1 is making A_{FB} more negative
- the couplings to fermions are nontrivial
  - u-c-$\Delta_{6,1}$ have to be small so that no D-Dbar mixing contribs.
  - they arise at 1-loop then
  - also dijets constraints





04

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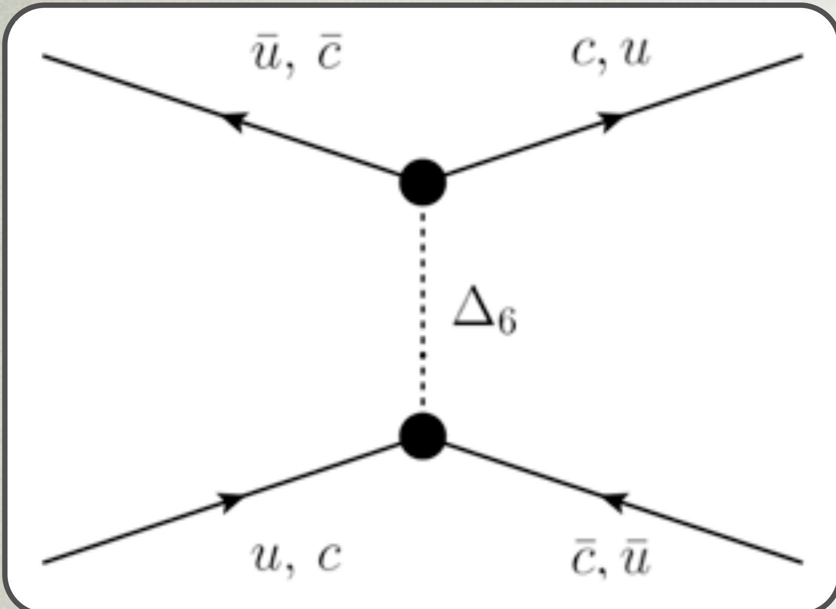

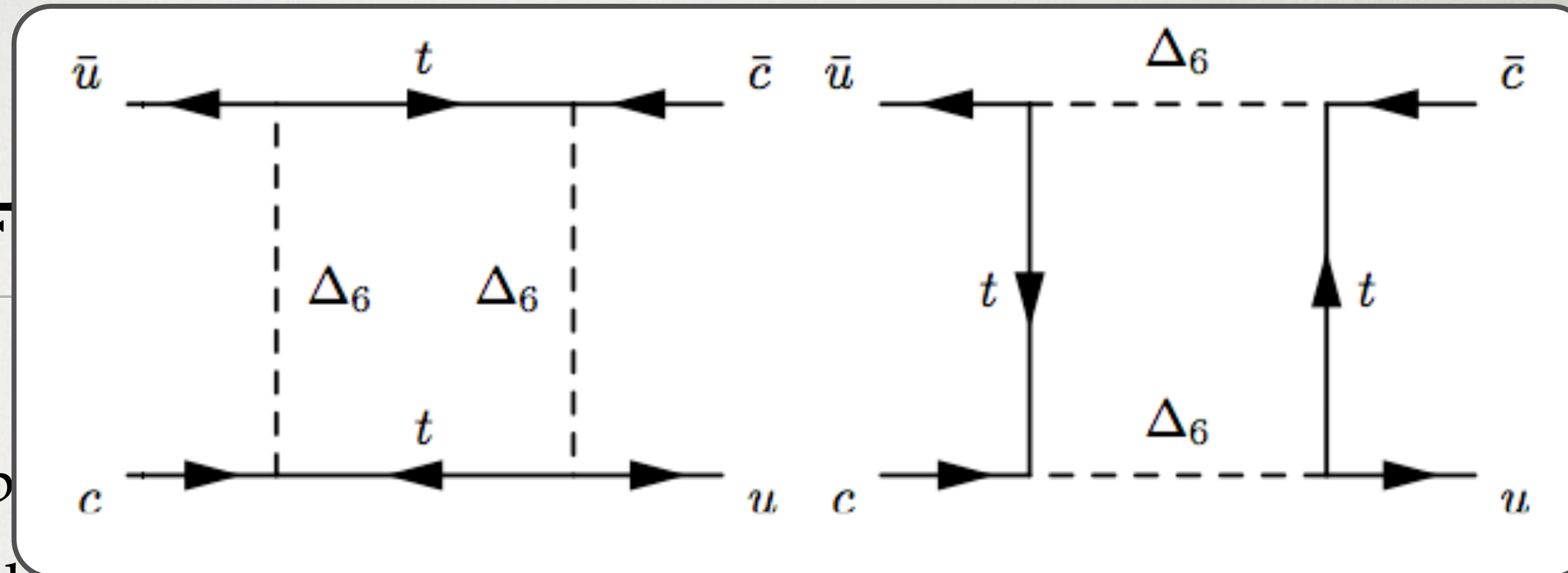

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$$|g_6^{13}| = 0.9(2) + 2.5(4)\frac{m_{\Delta_6}}{1\ \text{TeV}}$$

- also gives neutrino masses throu
- to have ... 0 GeV,

$$|g_6^{23}| < 0.0038$$

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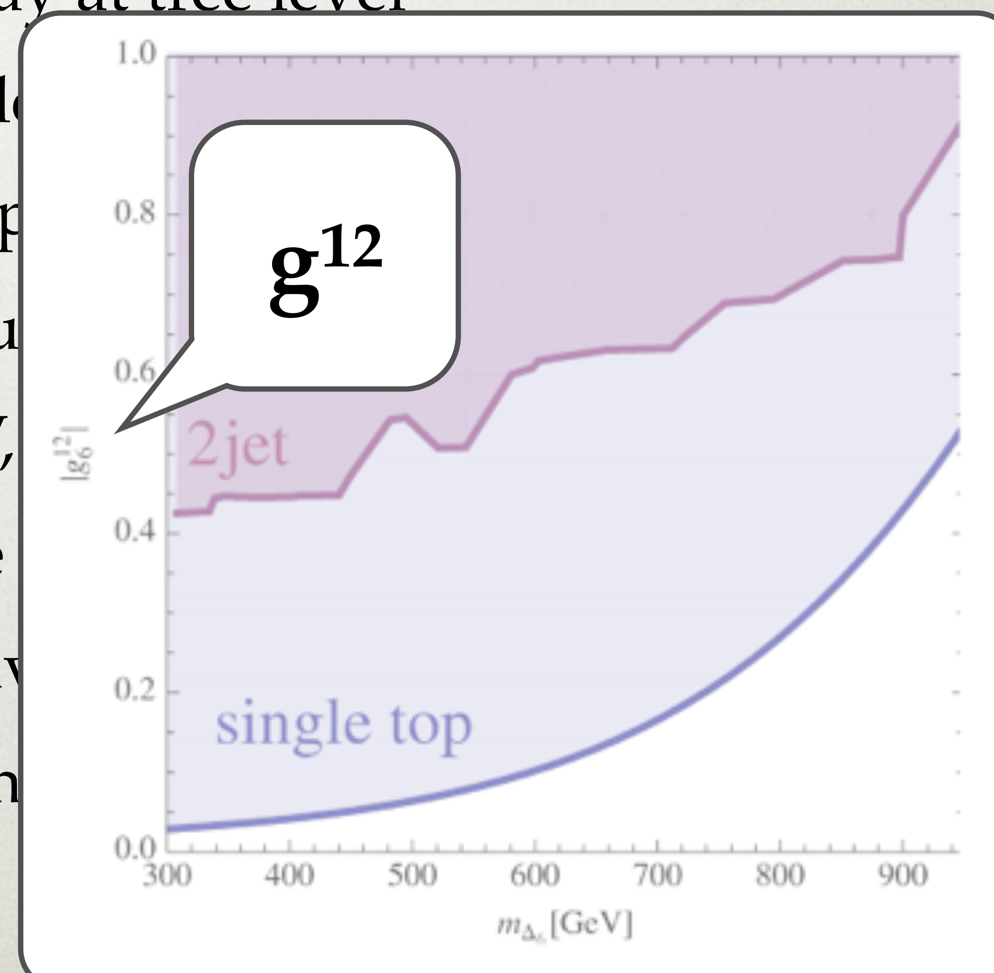


“Flavourful Production at Hadron Colliders”

Giudice, Gripaios, Sundrum, 1105.3161

- another example of large flavor violation
- focus on diquarks
- assume that couplings to quarks hierarchical in the same basis as yukawas are hierachical
  - depending on color assignment there may or may not be tree level FCNCs
- for A_{FB} most interesting the diquarks that couple antisymmetrically
  - “perverted hierarchy”
  - one needs “chiral hierarchy”

$$\mathcal{L} = -\Sigma_{i,j} \left(y^u_{ij} \epsilon^q_i \epsilon^u_j \overline{q}^i_L H u^j_R + y^d_{ij} \epsilon^q_i \epsilon^d_j \overline{q}^i_L H^c d^j_R \right) + \text{h.c.},$$

“Flavourful Production at Hadron Colliders”

Sundrum, 1105.3161

Hierarchy	CKM-like	Chiral hierarchy
Inverted	$(\lambda_3^u)^2 \lesssim 10\ (D)$	$(\lambda_3^u)^2 \lesssim 90\ (D)$
Normal	$(\lambda_1^u)^2 \lesssim 0.03\ (D)$	$(\lambda_1^u)^2 \lesssim 0.7\ (D)$
Perverted	$(\lambda_2^u)^2 \lesssim 0.03\ (D)$	$(\lambda_2^u)^2 \lesssim 0.7\ (D)$
Inverted	$(\lambda_3^d)^2 \lesssim 2\ (B_d)$ $\lambda_3^d \lesssim 1\ (B \to \phi\pi)$	$(\lambda_3^d)^2 \lesssim 0.06\ (K)$ $\lambda_3^d \lesssim 0.3\ (B \to \phi\pi)$
Normal, Perverted	$(\lambda_{1,2}^d)^2 \lesssim 0.01\ (K)$ $\lambda_{1,2}^d \lesssim 1\ (B \to \phi\pi)$	$(\lambda_{1,2}^d)^2 \lesssim 0.01\ (K)$ $\lambda_{1,2}^d \lesssim 0.3\ (B \to \phi\pi)$

TABLE III: Bounds (with the process in parentheses) on the largest diquark coupling in units of M/TeV, for each of the three hierarchies, for CKM-like mixing and Chiral Hierarchy. The couplings are defined in eq'ns (8,12).

- one needs "chiral hierarchy"

$$\mathcal{L} = -\Sigma_{i,j}\left(y_{ij}^u \epsilon_i^q \epsilon_j^u \bar{q}_L^i H u_R^j + y_{ij}^d \epsilon_i^q \epsilon_j^d \bar{q}_L^i H^c d_R^j\right) + \text{h.c.},$$

FLAVOR CONSERVING MODELS

- $t\bar{t}$ production is not flavor violating
  - so why flavor violating models?
- in **s-channel**: to have $A_{FB}>0 \Rightarrow$ coupl. to $q\bar{q}$ opposite to $t\bar{t}$

  Cao, McKeen, Rosner, Shaughnessy, Wagner, 1003.3461 Bai, Hewett, Kaplan, Rizzo, 1101.5203
  - is flavor diagonal but not flavor universal!
  - so inherent flavor violation to the model is likely
- in **t-channel**: large *u-t (d-t)* couplings
  - in concrete models one has to worry about FCNCs

    Dorsner, Fajfer, Kamenik, Kosnik, 1007.2604
    - option 1): make *c-t* and u-c coupls. small

      Shelton, Zurek, 1101.5392

      Jung, Pierce, Wells, 1103.4835 Jung, Murayama, Pierce , Wells, 0907.4112 Gresham, Kim, Zurek, 1102.0018
    - option 2): protected by flavor symmetry

      Grinstein, Kagan, Trott, JZ, 1102.3374 Delaunay, Gedalia, Lee, Perez, Ponton, 1101.2902

      Babu, Frank, Kumar Rai, 1104.4782 Ligeti, Schmaltz, Tavares, 1103.2757

Generally

Grinstein, Kagan, Trott, JZ, 1102.3374

- a quick general analysis:
  - assume SM flavor symmetries
  - list all possible scalar and vector fields that can couple to quarks renormal.
- vectors: 22 possibilites
- scalars: 14 possibilities
- most of these could contribute to/generate A_{FB}
- will focus only on two
  - vector color octet, octet of flavor
  - scalar color sextet, sextet of flavor
- for concreteness for flavor breaking we can assume MFV
  - the exact form not really essential, just that is small

MFV scalars

Case	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$SU(3)_{U_R} \times SU(3)_{D_R} \times SU(3)_{Q_L}$	Couples to
I	1	2	1/2	$(3,1,\bar{3})$	$\bar{u}_R \quad Q_L$
II	8	2	1/2	$(3,1,\bar{3})$	$\bar{u}_R \quad Q_L$
III	1	2	-1/2	$(1,3,\bar{3})$	$\bar{d}_R \quad Q_L$
IV	8	2	-1/2	$(1,3,\bar{3})$	$\bar{d}_R \quad Q_L$
V	3	1	-4/3	$(3,1,1)$	$u_R \quad u_R$
VI	$\bar{6}$	1	-4/3	$(\bar{6},1,1)$	$u_R \quad u_R$
VII	3	1	2/3	$(1,3,1)$	$d_R \quad d_R$
VIII	$\bar{6}$	1	2/3	$(1,\bar{6},1)$	$d_R \quad d_R$
IX	3	1	-1/3	$(\bar{3},\bar{3},1)$	$d_R \quad u_R$
X	$\bar{6}$	1	-1/3	$(\bar{3},\bar{3},1)$	$d_R \quad u_R$
XI	3	1	-1/3	$(1,1,\bar{6})$	$Q_L \quad Q_L$
XII	$\bar{6}$	1	-1/3	$(1,1,3)$	$Q_L \quad Q_L$
XIII	3	3	-1/3	$(1,1,3)$	$Q_L \quad Q_L$
XIV	$\bar{6}$	3	-1/3	$(1,1,\bar{6})$	$Q_L \quad Q_L$

- vector color octet, octet of flavor
- scalar color sextet, sextet of flavor

- for concreteness for flavor breaking we can assume MFV
  - the exact form not really essential, just that is small

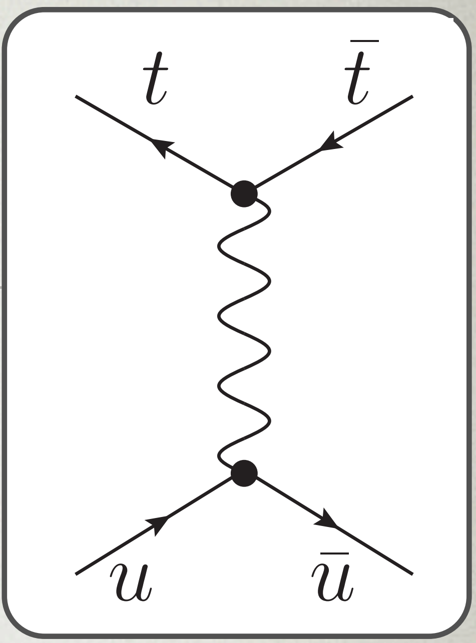
MFV scalars

Case	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$SU(3)_{U_R} \times SU(3)_{D_R} \times SU(3)_{Q_L}$	Couples to
I	1	2	1/2	$(3,1,\bar{3})$	$\bar{u}_R \quad Q_L$
II	8	2	1/2	$(3,1,\bar{3})$	$\bar{u}_R \quad Q_L$
III	1	2	-1/2	$(1,3,\bar{3})$	$\bar{d}_R \quad Q_L$
IV	8	2	-1/2	$(1,3,\bar{3})$	$\bar{d}_R \quad Q_L$
V	3	1	-4/3	$(3,1,1)$	$u_R \quad u_R$
VI	$\bar{6}$	1	-4/3	$(\bar{6},1,1)$	$u_R \quad u_R$
VII	3	1	2/3	$(1,3,1)$	$d_R \quad d_R$

MFV vectors

Case	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$SU(3)_{U_R} \times SU(3)_{D_R} \times SU(3)_{Q_L}$	Couples to
$\mathrm{I}_{s,o}$	1,8	1	0	$(1,1,1)$	$\bar{d}_R\, \gamma^\mu\, d_R$
$\mathrm{II}_{s,o}$	1,8	1	0	$(1,1,1)$	$\bar{u}_R\, \gamma^\mu\, u_R$
$\mathrm{III}_{s,o}$	1,8	1	0	$(1,1,1)$	$\bar{Q}_L\, \gamma^\mu\, Q_L$
$\mathrm{IV}_{s,o}$	1,8	3	0	$(1,1,1)$	$\bar{Q}_L\, \gamma^\mu\, Q_L$
$\mathrm{V}_{s,o}$	1,8	1	0	$(1,8,1)$	$\bar{d}_R\, \gamma^\mu\, d_R$
$\mathrm{VI}_{s,o}$	1,8	1	0	$(8,1,1)$	$\bar{u}_R\, \gamma^\mu\, u_R$
$\mathrm{VII}_{s,o}$	1,8	1	-1	$(3,3,1)$	$\bar{d}_R\, \gamma^\mu\, u_R$
$\mathrm{VIII}_{s,o}$	1,8	1	0	$(1,1,8)$	$\bar{Q}_L\, \gamma^\mu\, Q_L$
$\mathrm{IX}_{s,o}$	1,8	3	0	$(1,1,8)$	$\bar{Q}_L\, \gamma^\mu\, Q_L$
$\mathrm{X}_{\bar{3},6}$	$\bar{3}$,6	2	-1/6	$(1,3,3)$	$\bar{d}_R\, \gamma^\mu\, Q^c_L$
$\mathrm{XI}_{\bar{3},6}$	$\bar{3}$,6	2	5/6	$(3,1,3)$	$\bar{u}_R\, \gamma^\mu\, Q^c_L$

FORWARD BACKWARD ASYMMETRY



- these fields have *O(1)* coupls. to quarks (all gens.)
- an example: **flavor singlet vector (*s*-channel)**

$$\bar{Q}_L\,\gamma^\mu\,Q_L V_\mu = \bar{t}_L\,\gamma^\mu\,t_L + \bar{u}_L\,\gamma^\mu\,u_L + \cdots$$

  - need breaking : yukawas can flip the sign of *ttbar* coupling

$$\bar{Q}_L\,\gamma^\mu\,Y_U^\dagger Y_U Q_L V_\mu = y_t^2 \bar{t}_L\,\gamma^\mu\,t_L$$

- our example: **flavor octet vector (*s*-channel)**

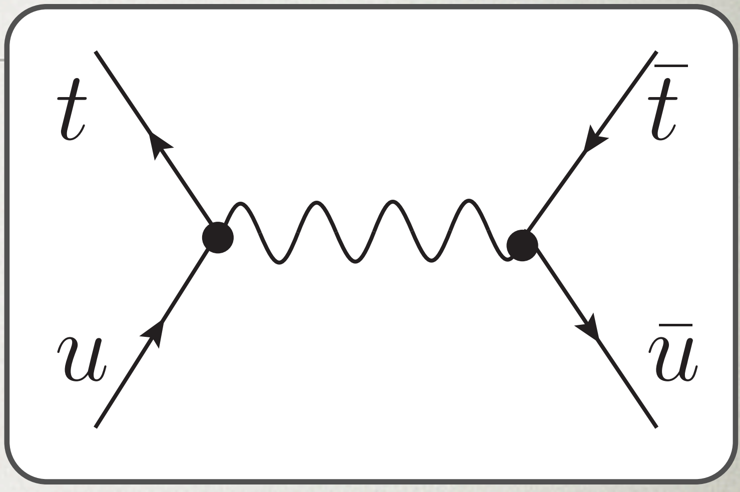
$$(\bar{Q}_L\,T^A \gamma^\mu Q_L) V_\mu^A = \frac{1}{\sqrt{3}} V_\mu^8 \big(\bar{u}_L\,\gamma^\mu\,u_L + \bar{c}_L\,\gamma^\mu\,c_L - 2\bar{t}_L\,\gamma^\mu\,t_L\big) + \ldots$$

  - the sign of coupl. to top pair is opposite to the one for *u*,*c*
  - this is without any flavor violation (no yukawa insertions)

FORWARD BACKWARD ASYMMETRY

- **flavor octet: *t*-channel**

$$(\bar{Q}_L\, T^A \gamma^\mu Q_L) V^A_\mu = (V^4_\mu - i V^5_\mu)(\bar{t}_L\, \gamma^\mu\, u_L) + \ldots$$



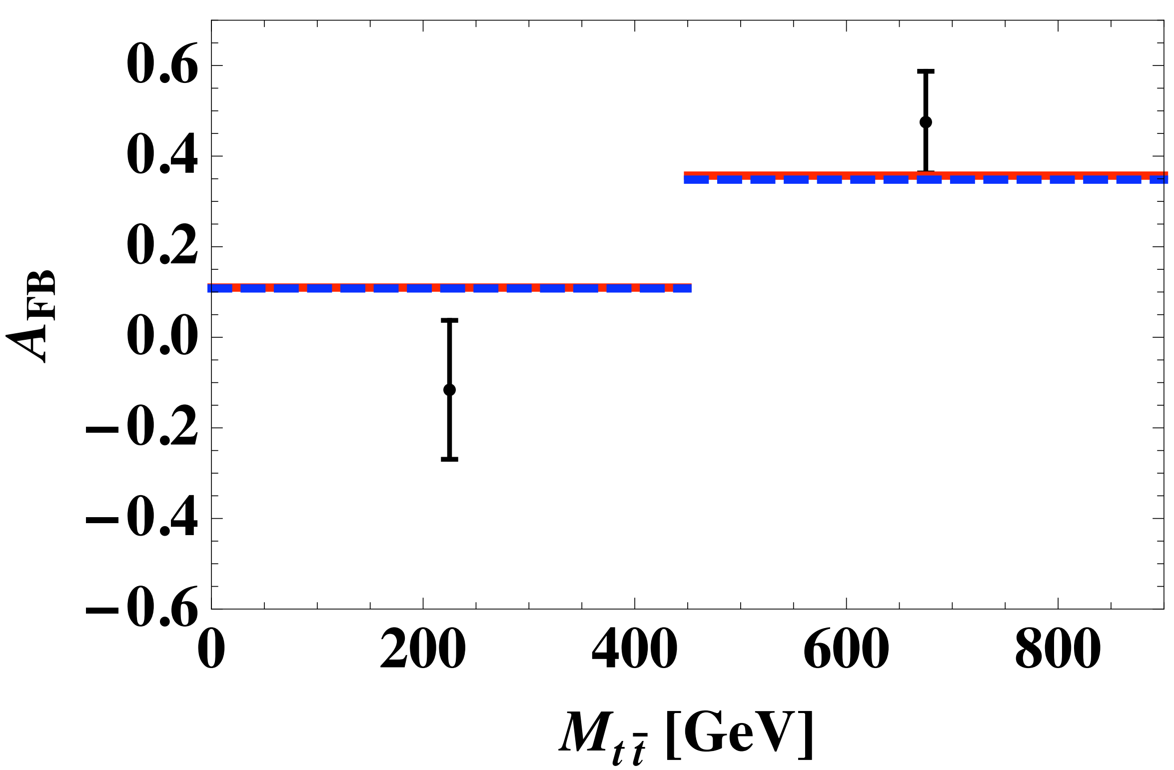
  - *O(1)* flavor changing term (no CKMs)
- so why no FCNCs?
- in the flavor symmetric limit the propagator

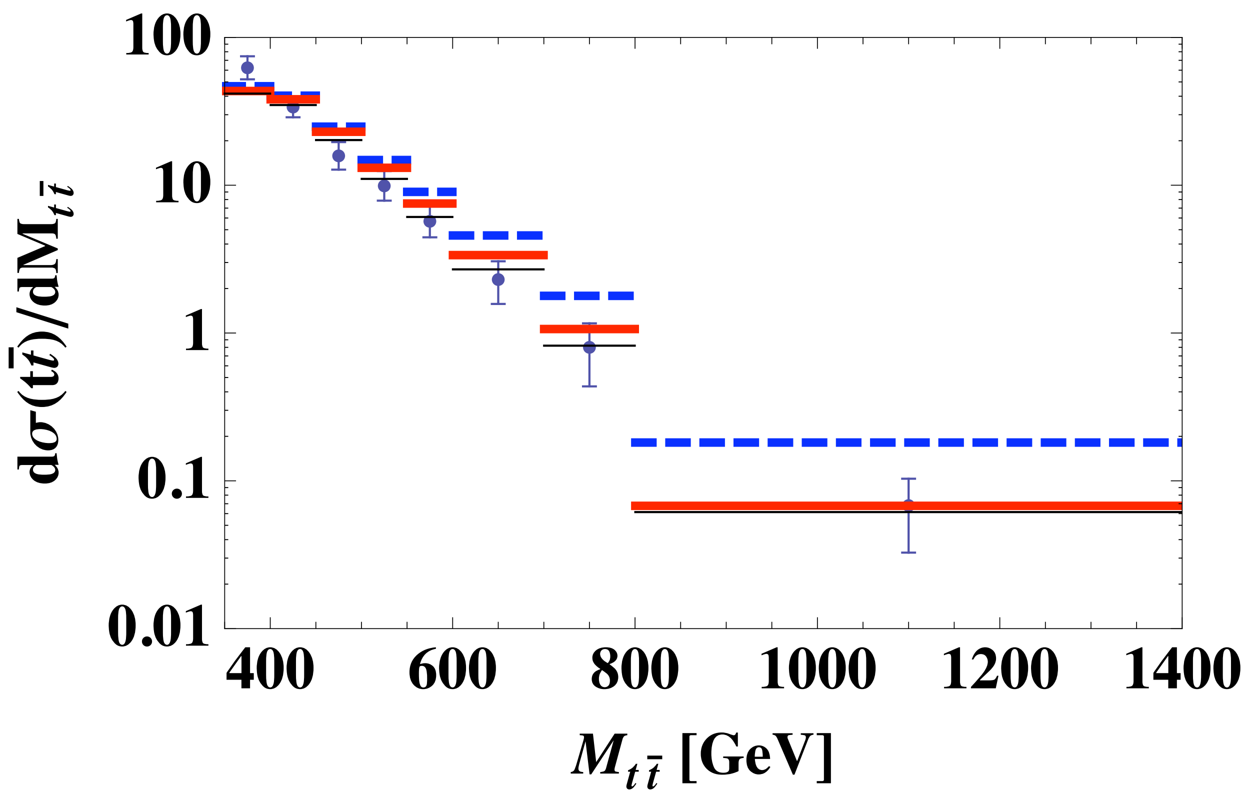
$$(\bar{q}_i q_j \longrightarrow \bar{q}_l q_k) \propto \ldots \delta_{ij}\delta_{lk} + \ldots \delta_{il}\delta_{jk}$$

  - there are no ΔF=2 amplitudes unless G_F broken
  - e.g. for B_s mixing would need $(\bar{s}b)^2$

VECTOR OCTET

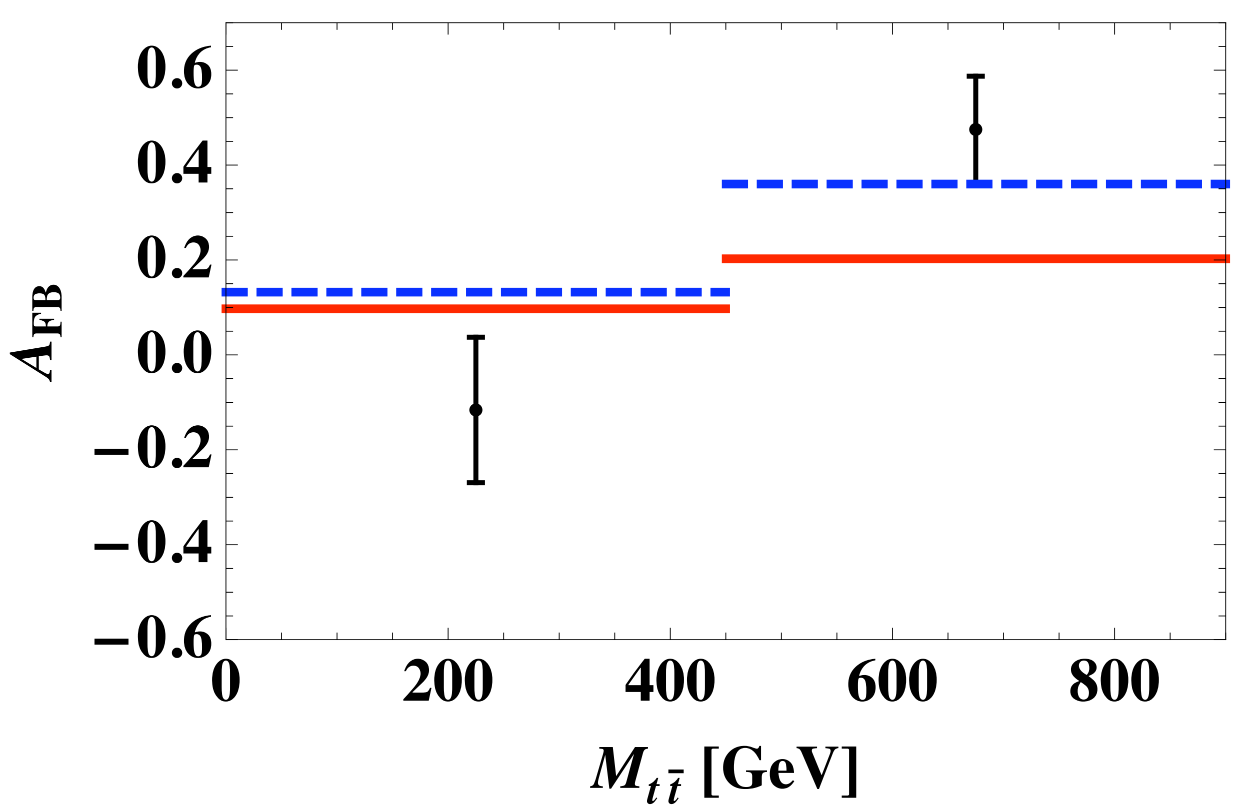
- an example: vector, octet of color, *(8,1,1)* of flavor (couples to $\bar{u}_R u_R$)
- plots $(m_V,\ (\eta_{ab}\eta_{33})^{1/2},\ \eta_{a3},\ \Gamma_V/m_V)$:
  - (300 GeV, 1,1.33, 0.08); (1200 GeV, 2.2, 4.88, 0.5)
- note: no large hierarchy in couplings
  - the difference natural due to y_t breaking

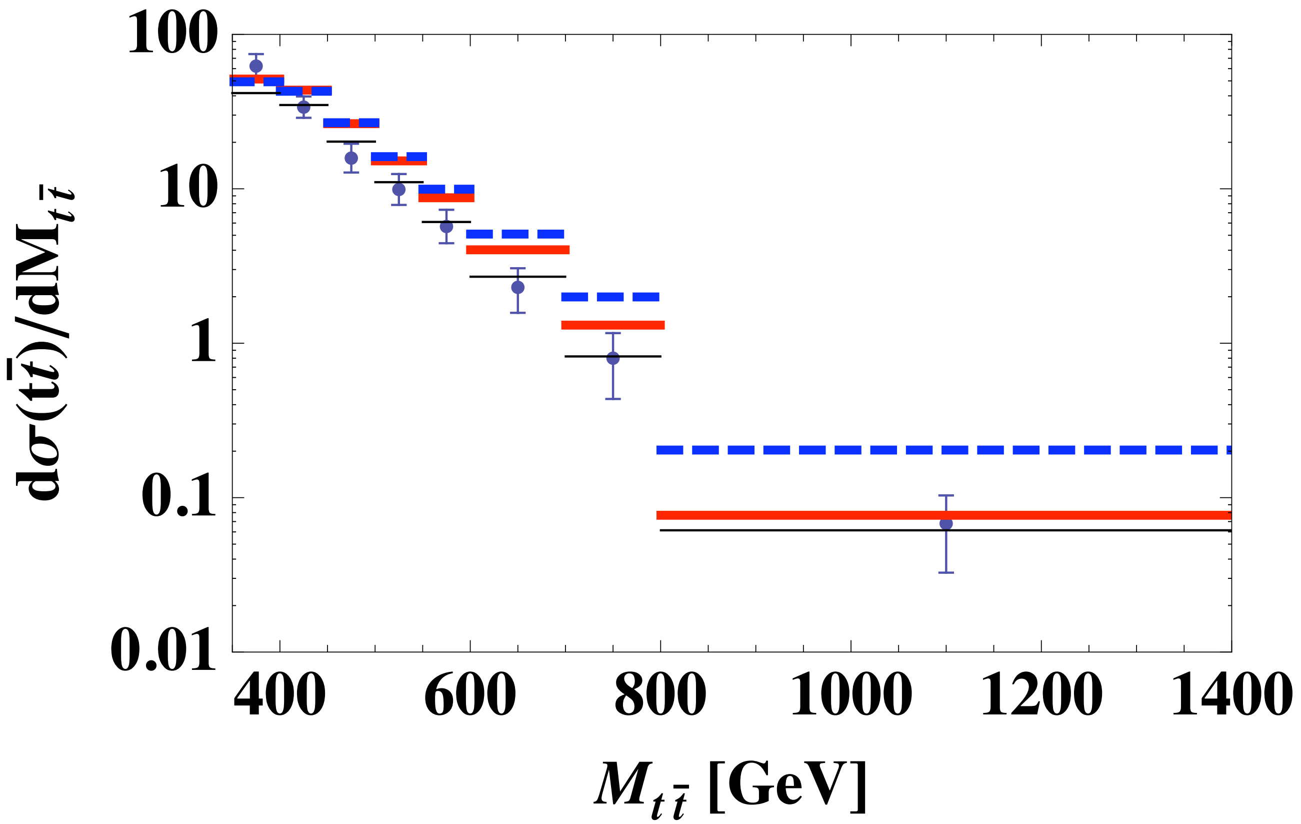




SEXTET SCALAR

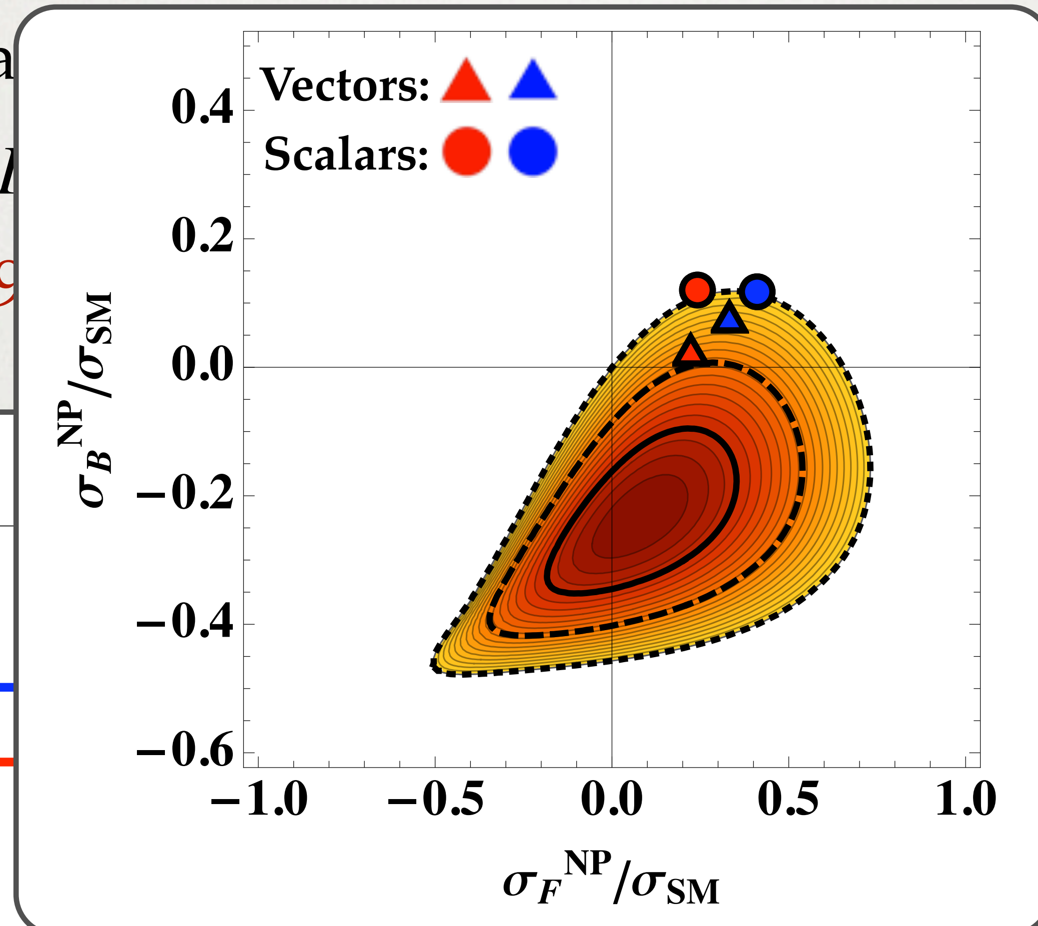
- an example: scalar, sextet of color, *(6,1,1)* of flavor (couples to $\bar{u}_R u_R$)
- plots $(m_S,\ \eta_{a3},\ \Gamma_S/m_S)$:
  - (390 GeV, 1.95, 0.1); (1300 GeV, 4.9, 0.5)

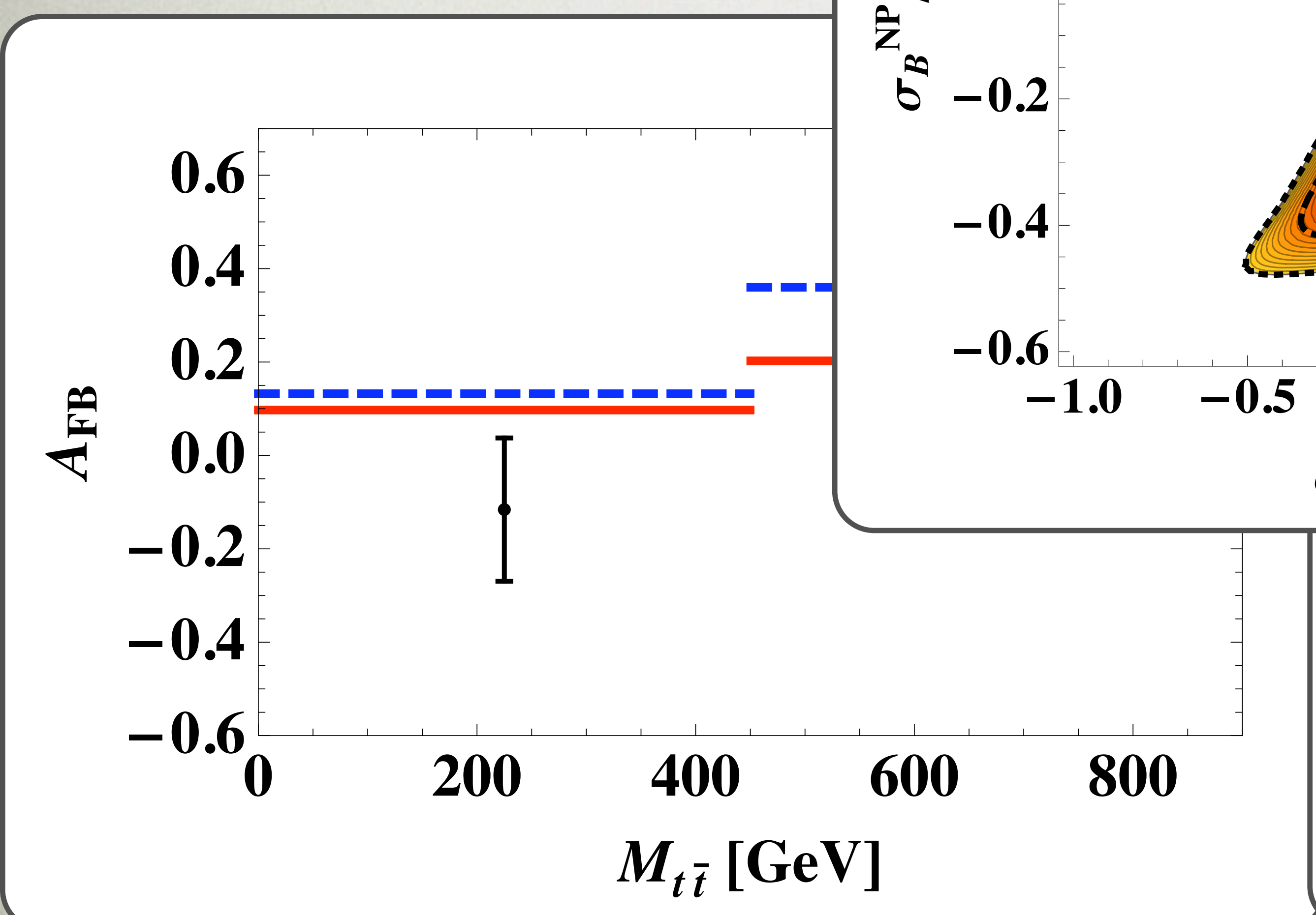


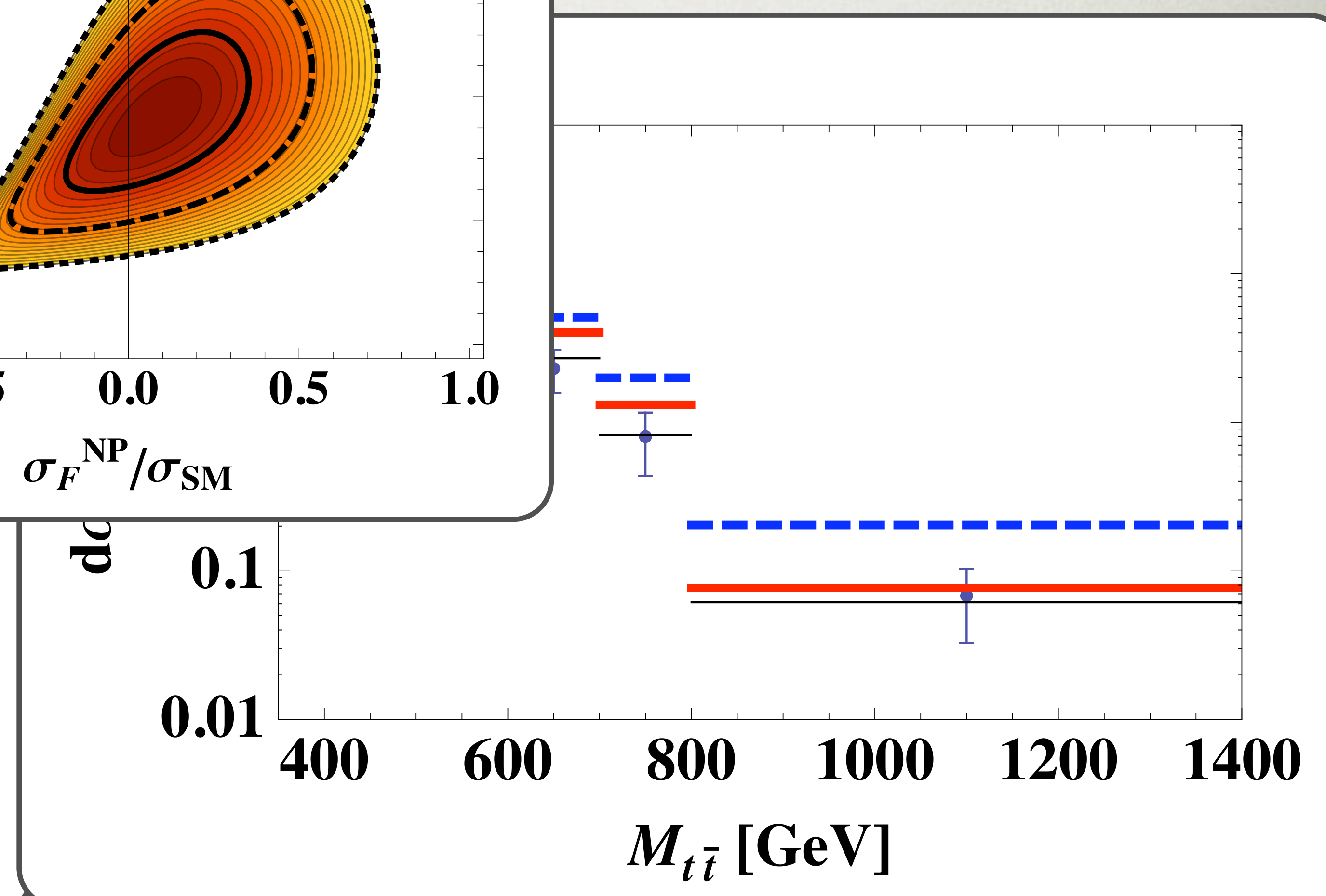


SEXTET SCALAR

- an example: sca ... couples to $\bar{u}_R u_R$)
- plots $(m_S,\ \eta_{a3},\ I$
    - (390 GeV, 1.9







OTHER OBSERVATIONS

Grinstein, Kagan, Trott, JZ, 1102.3374

- if V,S in nontrivial flavor representation ⇒ no like-sign top pairs (t-channel)
- since O(1) couplings to all generations: dijet constraints are potentially important
  - but small enough/below bounds
  - need some flavor breaking for the sextet scalars

Ligeti, Schmaltz, Tavares, 1103.2757

- can we explain B_s mixing anomaly?
  - using just one set of fields?
  - need to couple to Q_L

B_s mixing

Grinstein, Kagan, Trott, JZ, in preparation

- the set of models that involve Q_L: possible to generate B_s mixing anomaly
- need flavor breaking (here from MFV)
  - these MFV theories are protected against large FCNCs
  - effects naturally of the right order
  - need large tanβ (i.e. $y_b \sim O(1)$) for large phase
  - flavor universal phases needed

TYPICAL SCALES

- three classes of models
  - type-I operators: universal B_d and B_s

$$h_{d,s} e^{i2\sigma_{d,s}} \sim 0.2 \left(\frac{\eta}{0.1}\right)^2 \left(\frac{1\text{TeV}}{m_V}\right)^2$$

  - type-II operators: contribute just to B_s
    - linear in y_s

$$h_s e^{i2\sigma_s} \sim \eta^2 \left(\frac{y_s}{0.02 y_b}\right) \left(\frac{500\text{GeV}}{m_V}\right)^2$$

    - quadratic in y_s

$$h_s e^{i2\sigma_s} \sim 0.05\, \eta^2 \left(\frac{y_s}{0.02 y_b}\right)^2 \left(\frac{500\text{GeV}}{m_V}\right)^2$$

- the couplings are different than in $t\bar{t}$ production

INCOHERENT PRODUCTION

- A_{FB} due to incoherent production of ttbar+invisible — Isidori, Kamenik, 1103.0016
    - at present cannot give better than 2σ agreement with exp.
    - somewhat comparable with other *t*-channel models
- one needs large A_{FB} in new sector (ideally ~100%)
    - necessarily from light *t*-channel
    - stop (200 GeV) + $SU(2)_L x U(1)_Y$ singlet (2 GeV)

$$\mathcal{L} = \mathcal{L}_{SM} + (D_\mu \tilde{t})^\dagger (D^\mu \tilde{t}) - m_{\tilde{t}}^2 \tilde{t}^\dagger \tilde{t} + \bar{\chi}^0 (i\gamma_\mu D^\mu)\chi^0 - m_\chi \bar{\chi}_c^0 \chi^0 + \sum_{q=u,c,t} (\tilde{Y}_q \bar{q}_R \tilde{t} \chi^0 + \text{h.c.}) ,$$

- the production process is $p\bar{p} \to \tilde{t}\tilde{t}^\dagger \to t\bar{t}\chi^0\chi^0$
    - extra MET changes ttbar spectrum, could be used for detection - at present not sensitive yet
- χ can be a dark matter candidate, but not a simple thermal relic

INCO ... I

- A_{FB} due to ... enik, 1103.0016
  - at prese...
  - somewh...
- one needs ...
  - necessa...
  - stop (20...

$\mathcal{L} = \mathcal{L}_{S}$ ...

$-$ ...

- the produc...
  - extra M... detectio...

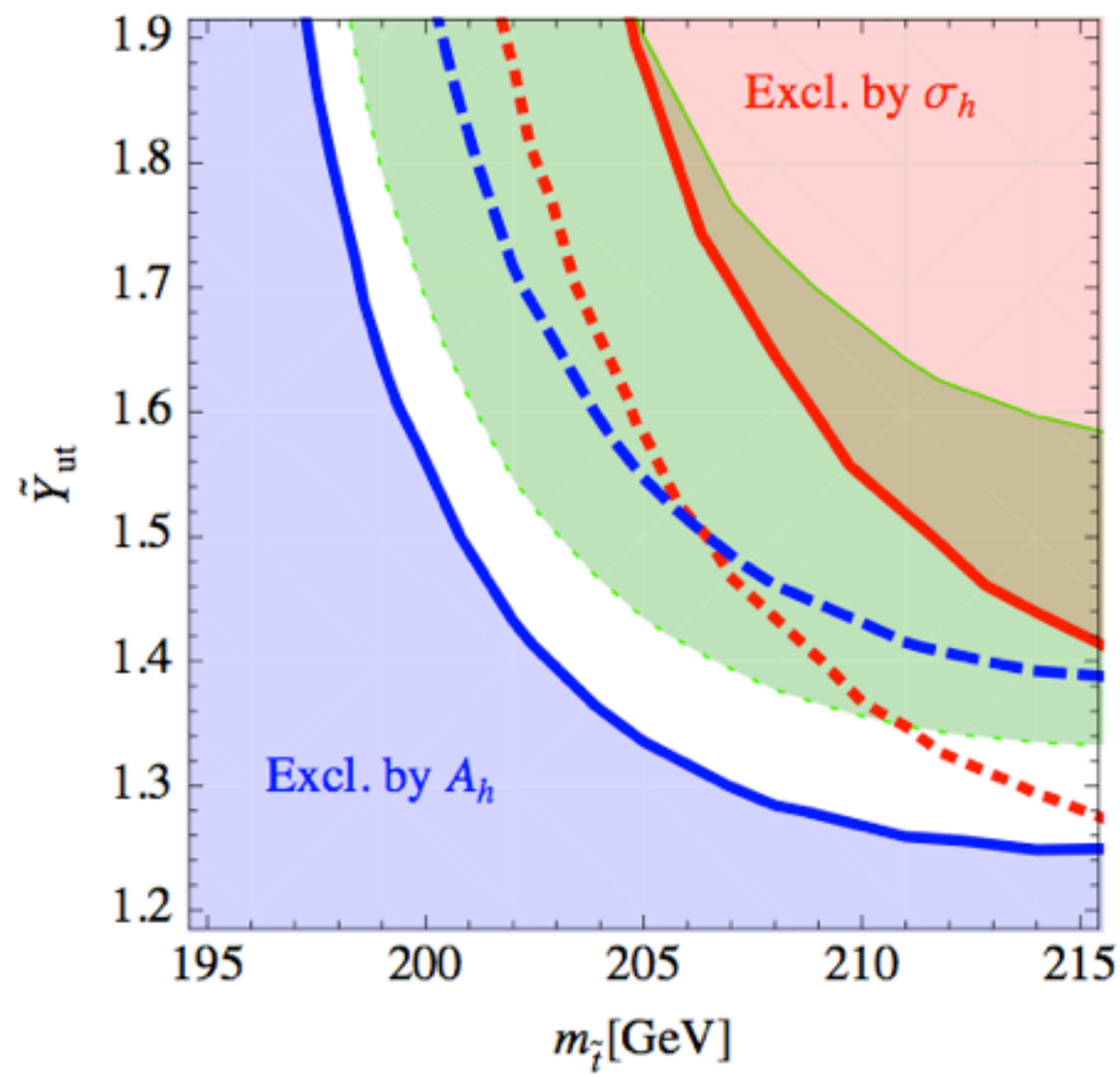


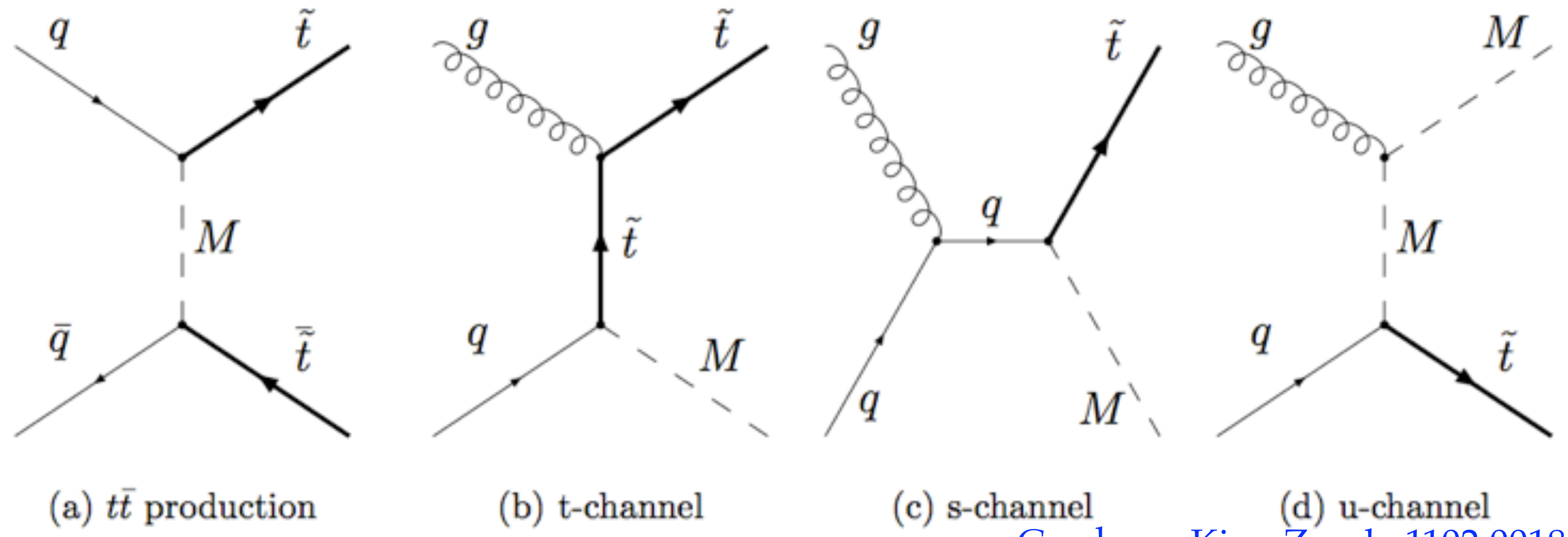
Figure 1. Tevatron constraints in the $m_{\tilde{t}}$–$\tilde{Y}_u$ plane. The inclusive $A_{FB}^{t\bar{t}}$ and $\sigma^{t\bar{t}}$ are reproduced within 1 σ in the central green band. The region below the continuous (dashed) blue line is excluded by A_h at 95% C.L. (90% C.L.). The region above the continuous (dotted) red line is excluded by σ_h at 95% C.L. (90% C.L.).

- χ can be a dark matter candidate, but not a simple thermal relic

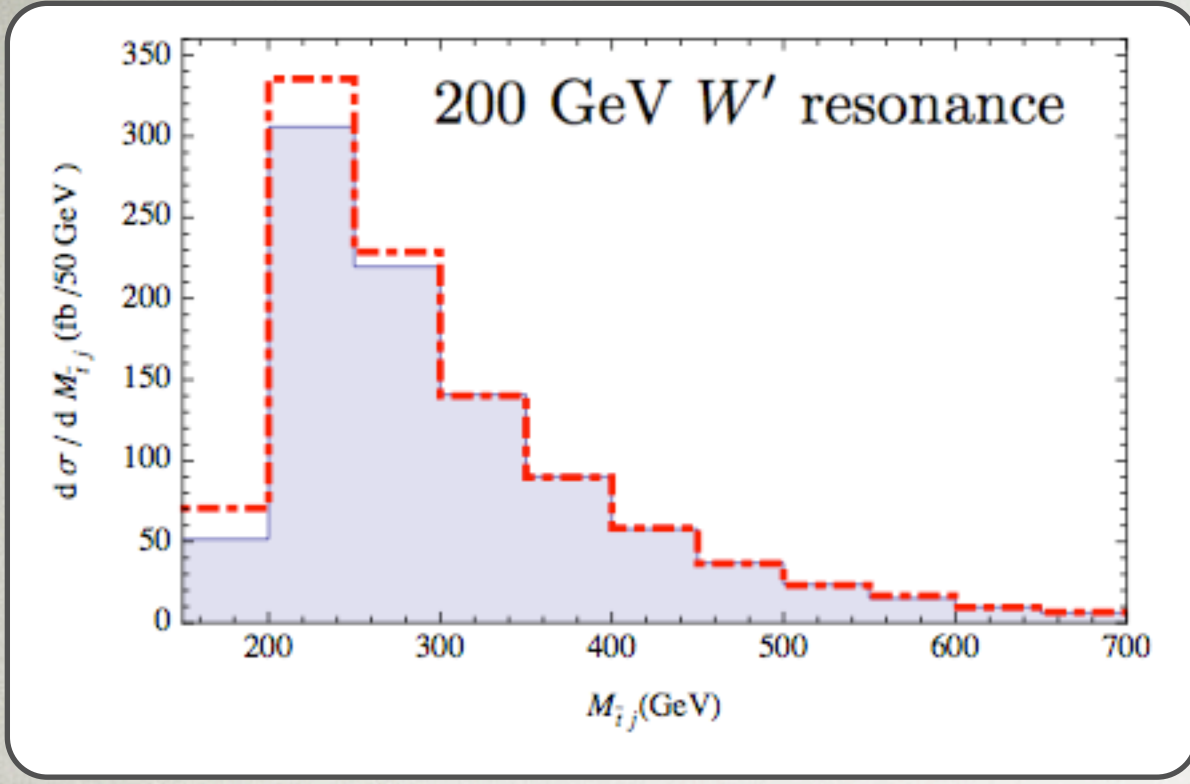
ADDITIONAL SIGNALS AT COLLIDERS

- some signals are quite generic for many *t*-channel models
  - a t+j resonance in $pp \to t\ tbar + j$
  - in addition use also distrib. in $cos\theta_{tj}$

Dorsner, Fajfer, Kamenik, Kosnik, 0912.0972
Gresham, Kim, Zurek, 1102.0018



Gresham, Kim, Zurek, 1102.0018



L S
LID

$$\mathcal{L}_{W'} = \frac{1}{\sqrt{2}} \bar{d}\gamma^\mu g_R P_R t W'_\mu + \text{h.c.}$$

$$\mathcal{L}_{Z'_H} = \frac{1}{\sqrt{2}} \bar{u}\gamma^\mu g_R P_R t Z'_{H\mu} + \text{h.c.}$$

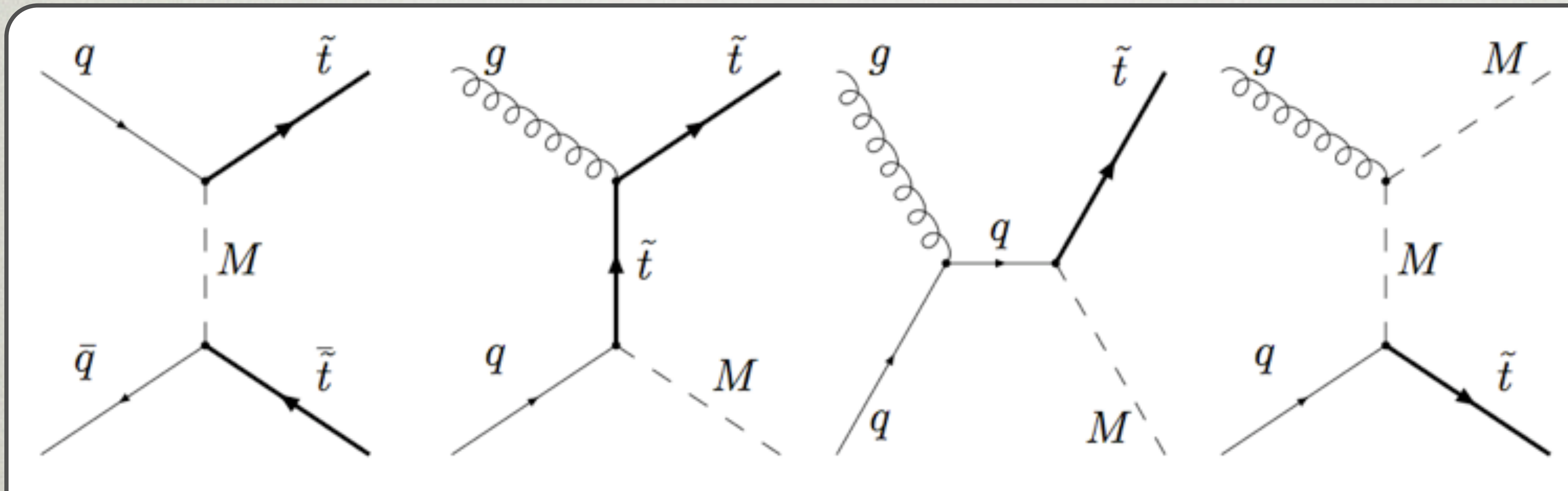
$$\mathcal{L}_\phi = \bar{t}^c T^a_r (g_L P_L + g_R P_R) u \phi^a + \text{h.c.},$$

te generic for many *t*-channel

- a *t+j* resonance in *pp→t tbar+j*

Dorsner, Fajfer, Kamenik, Kosnik, 0912.0972
Gresham, Kim, Zurek, 1102.0018

- in addition use also distrib. in $cos\theta_{tj}$

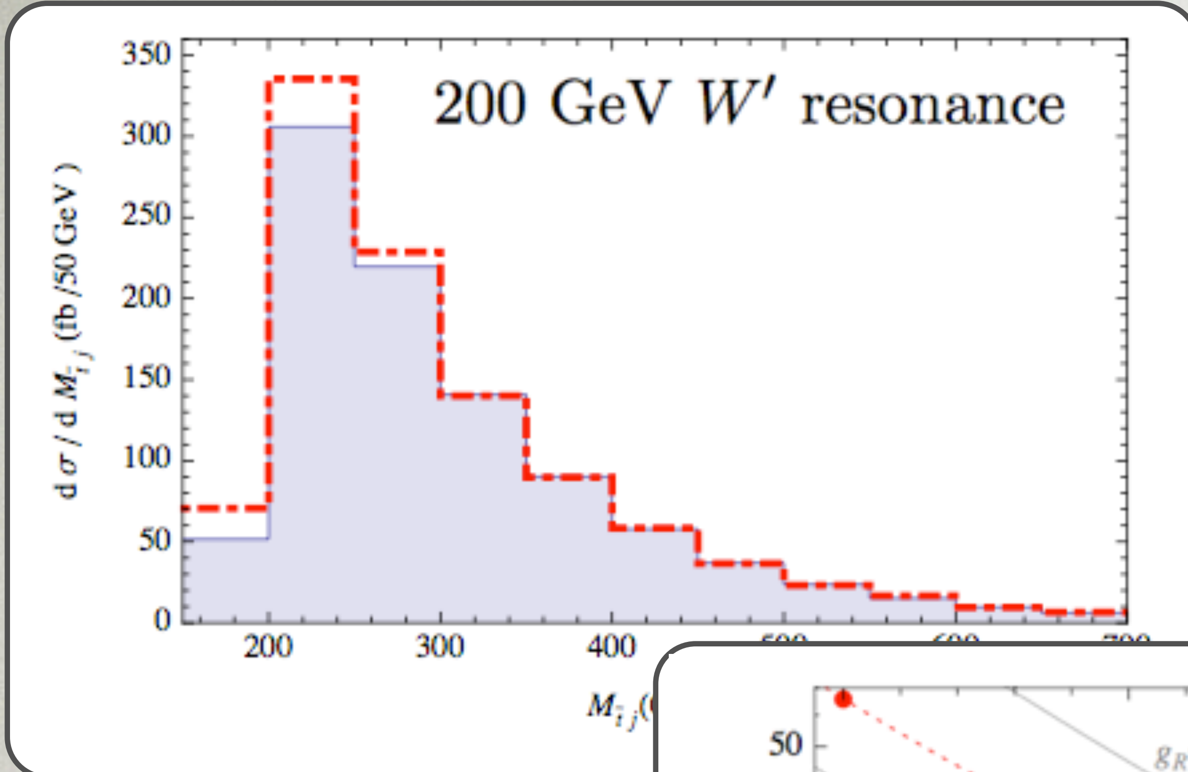


(a) $t\bar{t}$ production (b) t-channel (c) s-channel (d) u-channel

Gresham, Kim, Zurek, 1102.0018

L S

LID



$$\mathcal{L}_{W'} = \frac{1}{\sqrt{2}} \bar{d}\gamma^\mu g_R P_R t W'_\mu + \text{h.c.}$$
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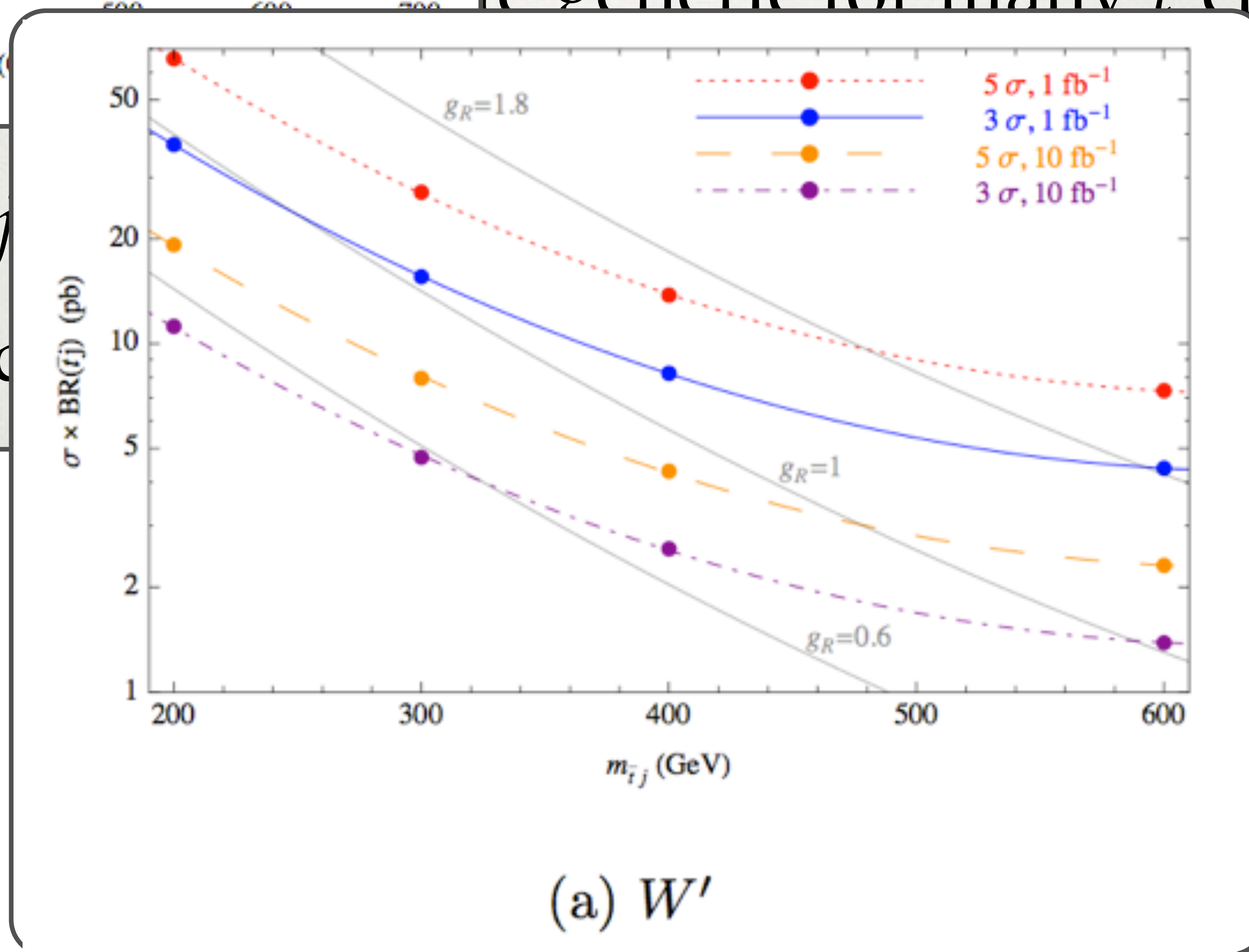
te generic for many *t*-channel

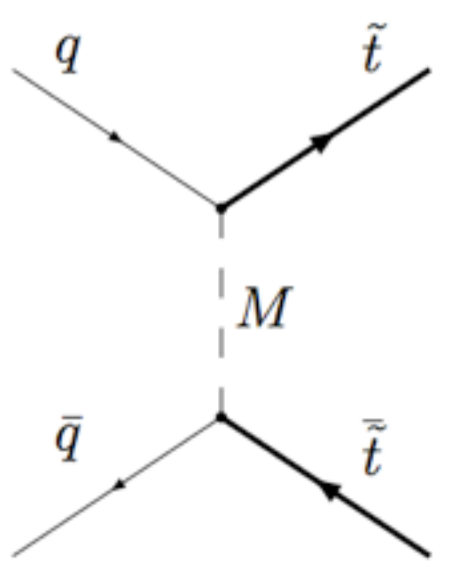
- a *t*+*j*
- in ac

menik, Kosnik, 0912.0972

n, Kim, Zurek, 1102.0018



(a) W'

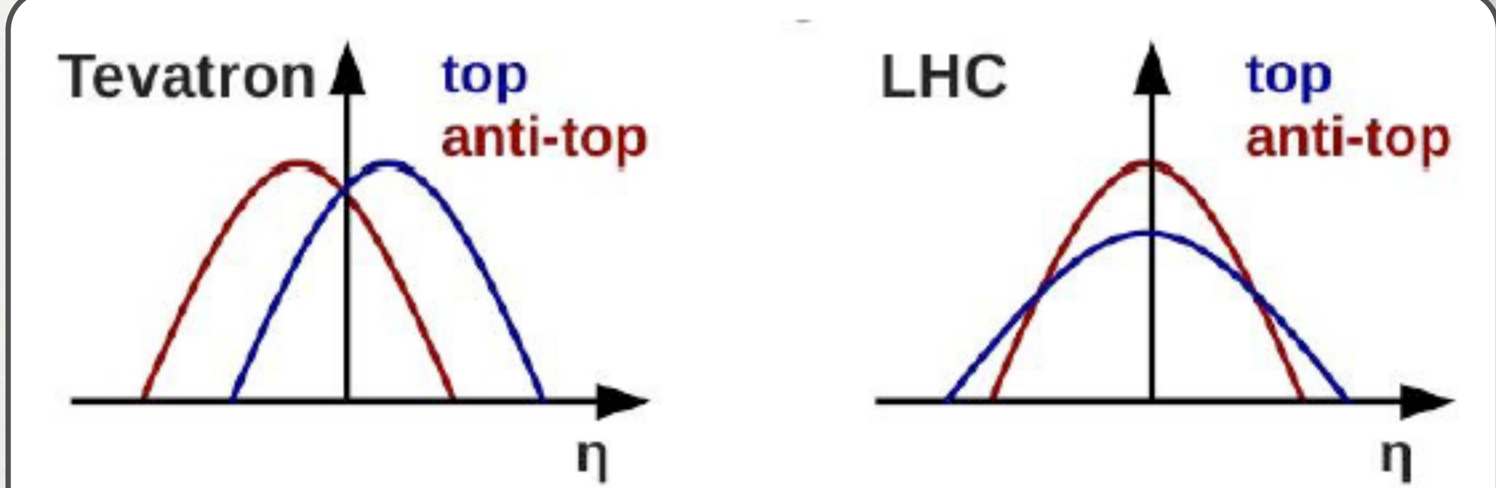


(a) $t\bar{t}$ production (b) t-channel (c) s-channel (d) u-channel

Gresham, Kim, Zurek, 1102.0018

ADDITIONAL SIGNALS AT COLLIDERS

- measurement of the ~A_{FB} directly at LHC
  - LHC: symmetric init. state
  - but the distribution in η is different



R. Chierici [CMS] talk at CERN, May 6th 2011

- so one can define charge asymmetry in the central region

$$A_C(y_C) = \frac{N_t(|y| \leq y_C) - N_{\bar{t}}(|y| \leq y_C)}{N_t(|y| \leq y_C) + N_{\bar{t}}(|y| \leq y_C)}$$

- Theory prediction for Standard Model (G. Rodrigo):
  A_c=0.0130(11)
  → only small asymmetry from NLO effects
  → only due to qqbar induced initial states
- An axigluon with mass >1TeV would yield
  A_c-A_c^{SM}~-0.02, -0.03

R. Chierici [CMS] talk at CERN, May 6th 2011

ADDITIONAL SIGNALS AT COLLIDERS

- with LHCb also possible to measure charge assymm. in very forward region
  - very forward region

Kagan, Kamenik, Perez, Stone, 1103.3747
see talks by J. Kamenik, A. Thuy Trang Phan

$$A_\eta^{t\bar{t}} = \left(\frac{d\sigma^t/d\eta - d\sigma^{\bar{t}}/d\eta}{d\sigma^t/d\eta + d\sigma^{\bar{t}}/d\eta} \right)_{\eta \in 2-5}$$

- another definition: asymmetry with respect to boost direction

Jung, Pierce, Wells, 1103.4835

$$A_{boost} = \frac{N(a>0) - N(a<0)}{N(a>0) + N(a<0)}, \qquad a \equiv (y_t + y_{\bar{t}})(y_t - y_{\bar{t}}).$$

$A_{boost} \cong 0.06$ at LHC7 for point A with $m_{t\bar{t}} \geq 450$ GeV

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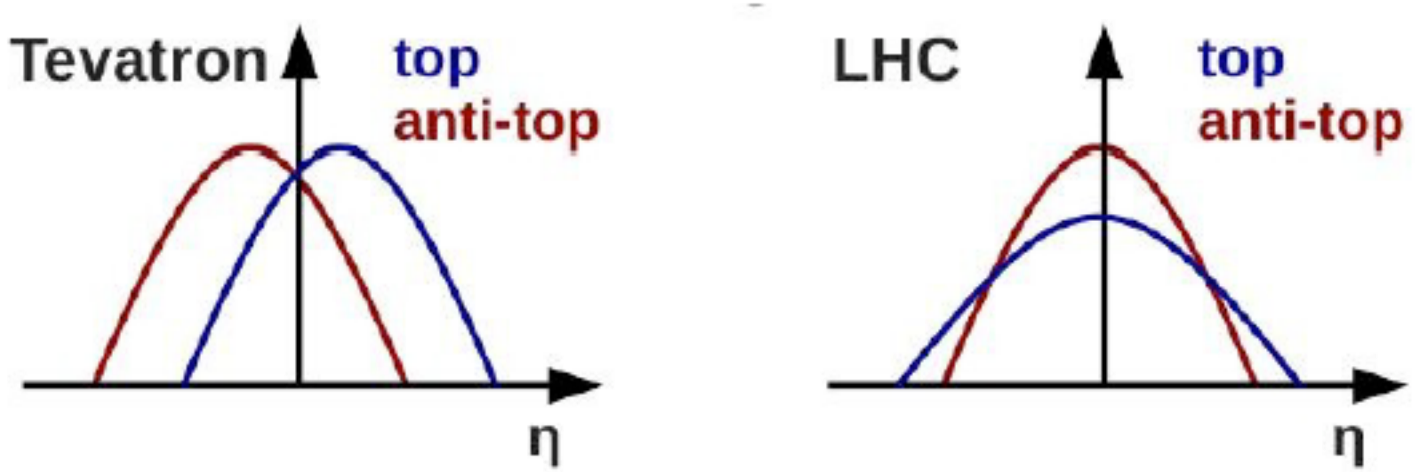
- ar ... ith re ...

Jung, Pierce, Wells, 1103.4835

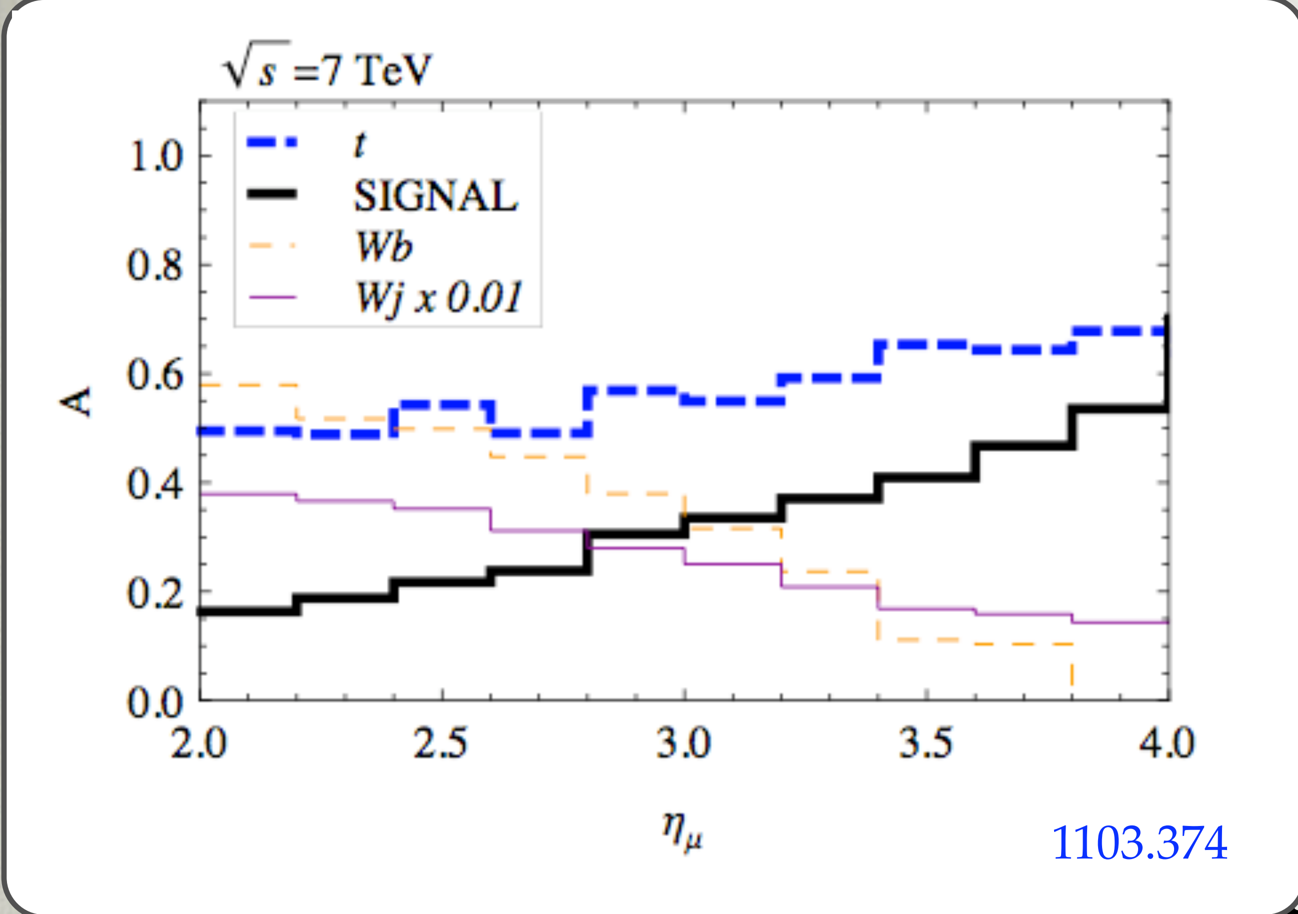


R. Chierici [CMS] talk at CERN, May 6th 2011

A ... $- y_{\bar t})$.

$A_{boost} \cong 0.06$ at LHC7 for point A with $m_{t\bar t} \geq 450$ GeV

SIGNALS AT
IDERS



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Kagan, Kamenik, Perez, Stone, 1103.3747
see talks by J. Kamenik, A. Thuy Trang Phan

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$A_{boost} \cong 0.06$ at LHC7 for point A with $m_{t\bar{t}} \geq 450$ GeV

ADDITIONAL SIGNALS

- other signals that may depend on the models
  - pair production of new states
  - single top production
  - if the states very light: top decays
  - potential for a signal in the presently constraining observables
    - dijets
    - like-sign tops
    - FCNCs
  - *t tbar*+*X* (e.g. *t tbar* +*MET*)

CONCLUSIONS

- if A_{FB} due to light *O(300 GeV)* states
  - vectors slightly preferred
- models with large flavor breaking and flavor conserving models

BACKUP SLIDES

FORWARD-BACKWARD ASYMMETRY

- CDF announced evidence for FBA in $t\bar{t}$ prod.

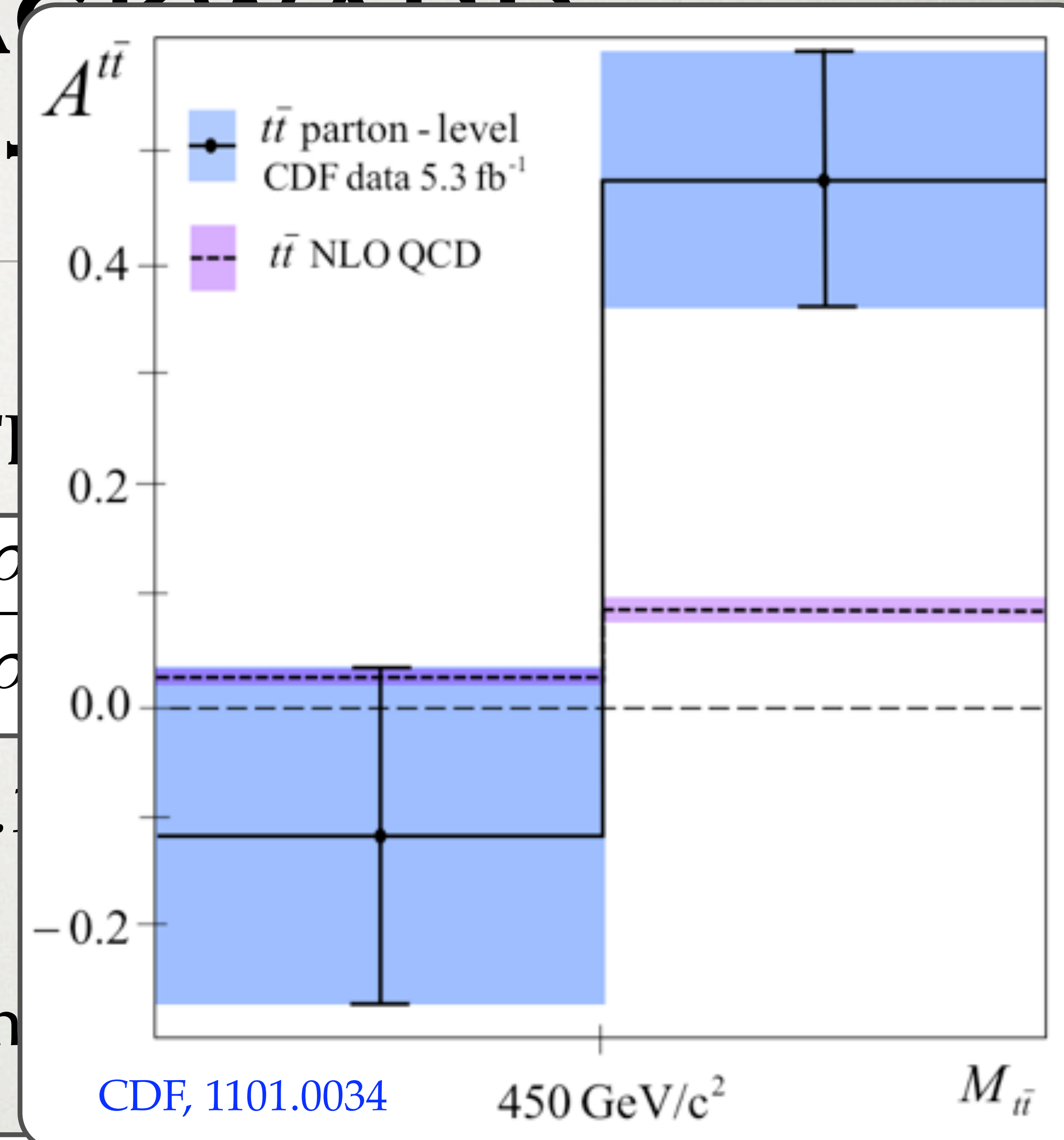
$$A^{t\bar{t}}_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

- for M_{tt}>450 GeV $A_{tt} = 0.475 \pm 0.114$ vs. SM@NLO: $A_{tt} = 0.088 \pm 0.013$ (3.4σ discr.)
- a new meaurm. in dileptonic channel (CDF@La Thuille 2011), inclusive:

$$A^{\Delta y_t}_{sub} = 0.205 \pm 0.073$$
$$\Rightarrow A^{\Delta y_t}_{true} = 0.417 \pm 0.148 \pm 0.053$$

- the challenge: cross section agrees well with the SM

FORWARD-BA
ASYMME



- CDF announced evidence for F

$$A^{t\bar{t}}_{FB} = \frac{\sigma_F - \sigma}{\sigma_F + \sigma}$$

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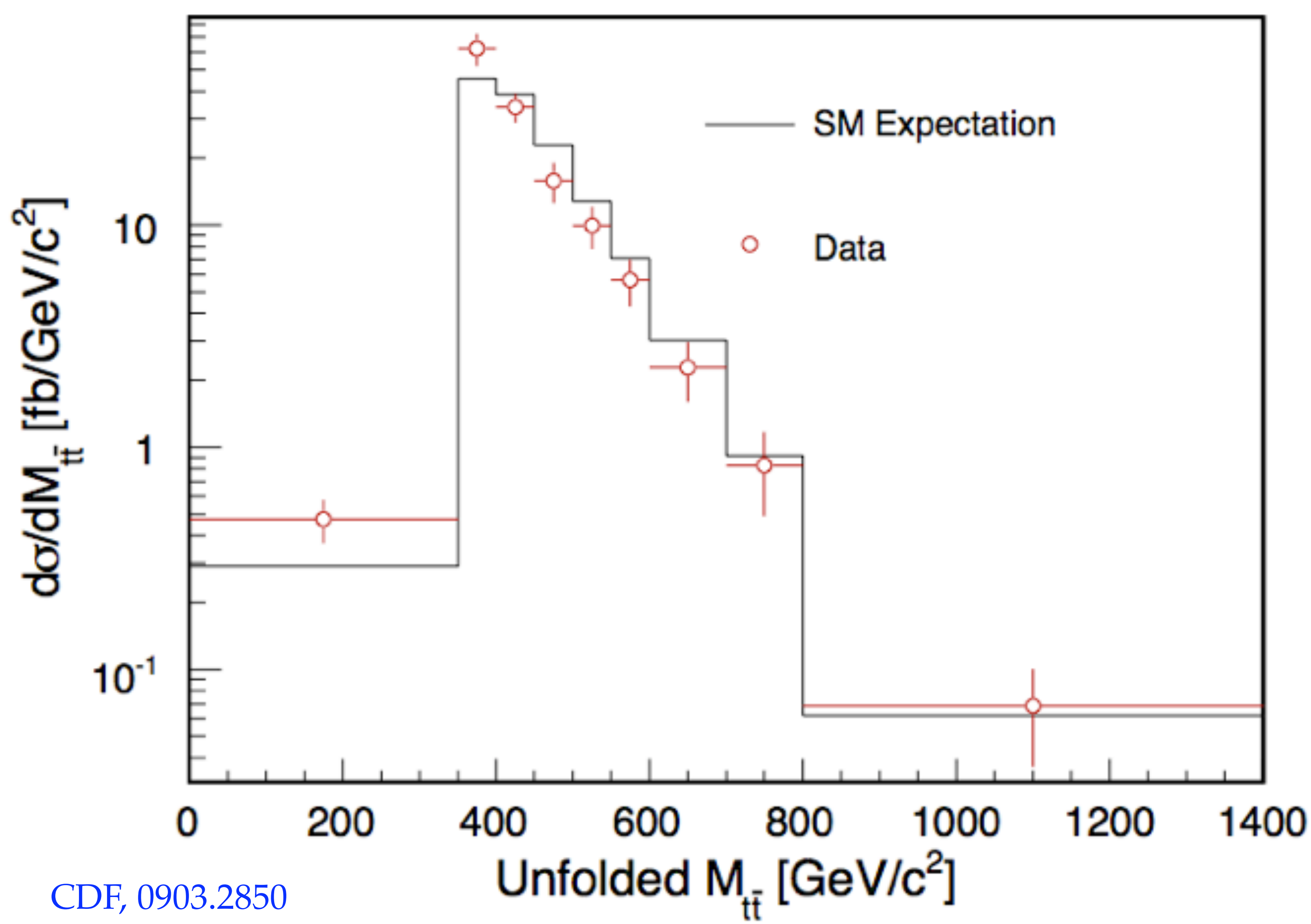
FORWARD-BACKWARD



CDF, 0903.2850

d
$t\bar{t}$

@NLO:

F@La Thuille

$\Rightarrow A_{true} = 0.417 \pm 0.148 \pm 0.053$

- the challenge: cross section agrees well with the SM