Comments on the Top quark forward backward asymmetry

Michael Trott

CERN

Based on:

Forward-backward asymmetry in t t production from flavour symmetries.
arXiv: 1102.3374 – Phys.Rev.Lett.107:012002,2011.
Benjamin Grinstein, Alexander L. Kagan, Michael Trott, Jure Zupan

Flavor Symmetric Sectors and Collider Physics.
arXiv: 1108.4027 – JHEP 1110:072,2011.
Benjamin Grinstein, Alexander L. Kagan, Michael Trott, Jure Zupan

EWPD Constraints on Flavor Symmetric Vector Fields.
arXiv: 1110.5361 – JHEP 1111:139,2011.
Benjamin Grinstein, Christopher W Murphy, Michael Trott

Electroweak Sudakov Corrections and the Top Quark Forward–Backward Asymmetry
arXiv: 1201.3926 – submitted to PRL
Aneesh V. Manohar, Michael Trott

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[redacted]27 – JHEP 1110:072,2011.

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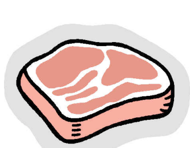


Electroweak Sudakov Corrections and the Top Quark Forward-Backward Asymmetry

arXiv: 1201.3926 – submitted to PRL

Aneesh V. Manohar, Michael Trott

Outline

1. Status of the top quark forward backward asymmetry $A_{FB}^{t\,\bar{t}}$ (& charge asym)

2. Status of the SM calculation of $A_{FB}^{t\,\bar{t}}$

3. EW Sudakov logs & large invariant mass observables

4. The refined room for new physics

5. Models that are (initially) flavour symmetric and $A_{FB}^{t\,\bar{t}}$.

Status of the top quark forward backward asymmetry

DISCLAIMER

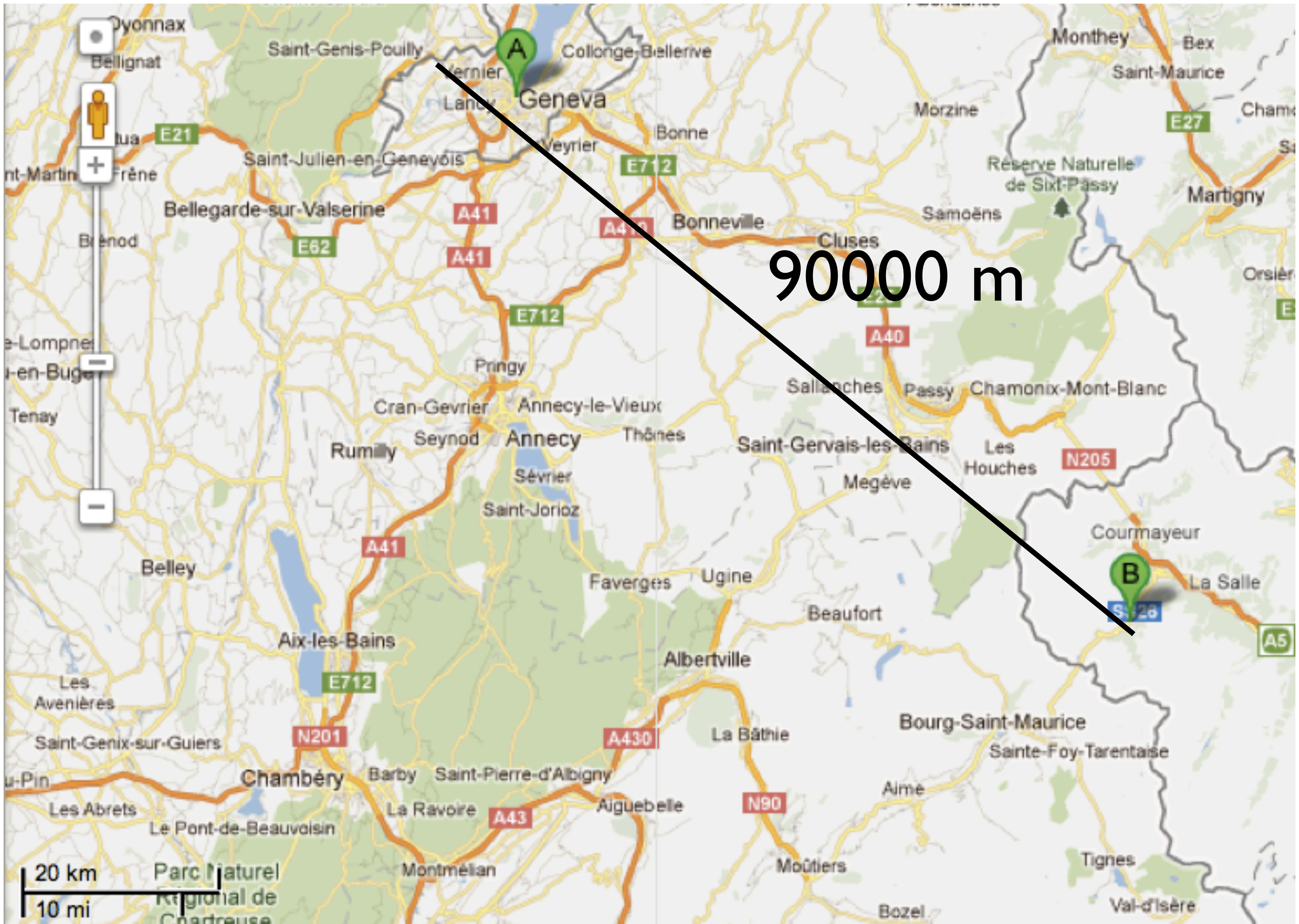
Subject to change: Moriond talks (now basically - or next friday)

Friday afternoon	***Top Physics, YSF4***
Sandra Leone	Top production (asymetry, single top, Vtb) at the Tevatron
German Rodrigo	ttbar asymmetry in the standard model and beyond
Viatcheslav Sharyy	Top properties (mass, width, spin correlations) at the Tevatron
Pedro Ferreira da Silva	Top physics in ATLAS and CMS
	Young Scientists Forum -4-

	09:50 - 10:05	Stijn Blyweert (Brussel)	Top Quark Mass Measurements at the LHC
F	10:10 - 10:30	*Coffee Break*	
	10:30 - 10:45	David Mietlicki (Michigan)	Measurements of Top Quark Properties at the Tevatron
R	10:50 - 11:05	Alison Lister (Geneva)	Measurements of Top Quark Properties at the LHC
	11:10 - 11:25	Ben Wu (Baylor)	Single Top Production at the Tevatron
I	11:30 - 11:45	Rebeca Gonzalez Suarez (Brussel)	Single Top Production at E_{cm}=7 TeV
D		Structure function, Spin, Diffraction, Forward physics session	
	17:00 - 17:15	Denys Lontkovskyi (DESY and Kiev)	Proton structure measurements at HERA
A	17:20 - 17:35	Mikhail Kapichine (JINR)	Diffraction and QCD precision measurements in ep scattering at HERA
	17:40 - 17:55	Mariusz Sadzikowski (Cracow)	Evidence for the higher twists effects in diffractive DIS at HERA
Y	18:00 - 18:15	Martin Hentschinski (Madrid)	Unintegrated sea quark at small x and forward Z production

Status of the top quark forward backward asymmetry

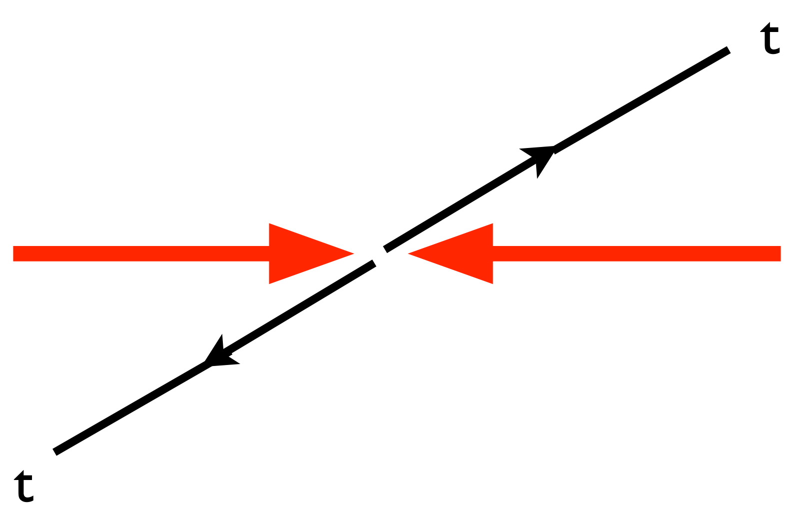
I have ~900000/c ~ 0.000300208 s in the worse case scenario.
(modulo those superluminal neutrino tendencies under the alps)

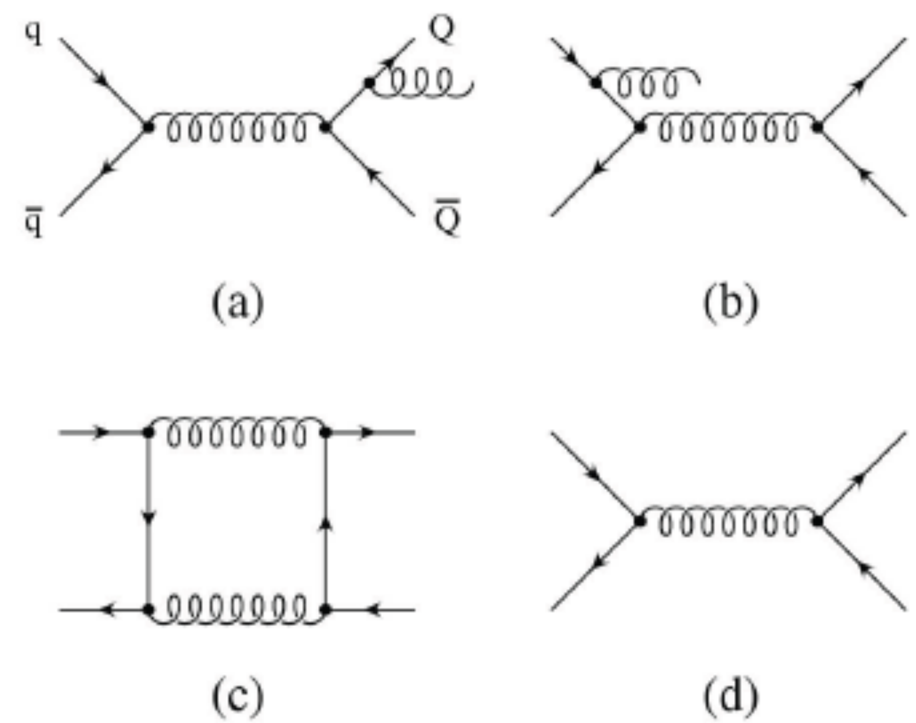


Status of the top quark forward backward asymmetry

Basic idea of what is being measured:

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



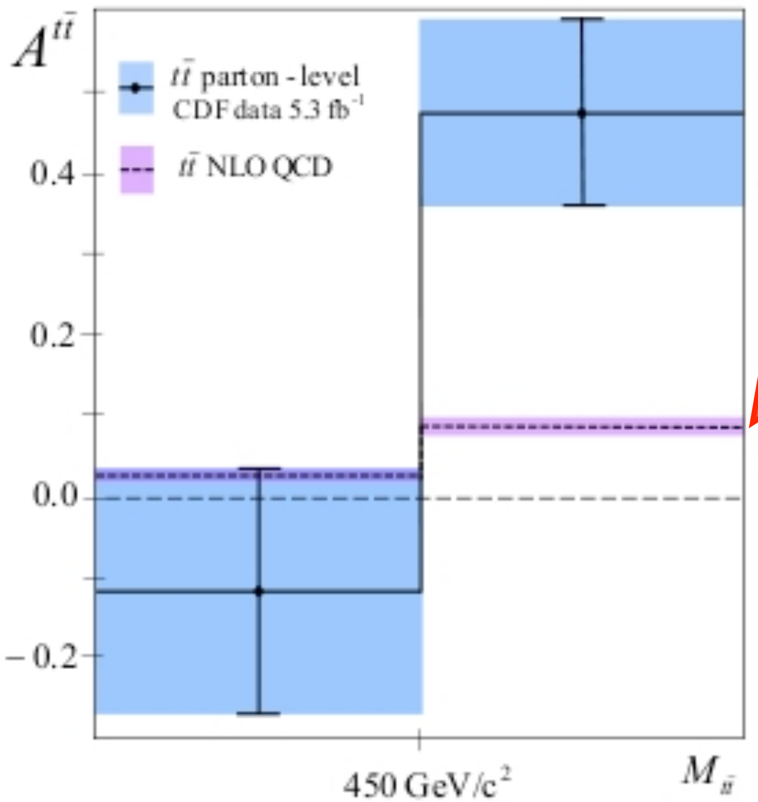


_1300 events with 5.3 fb^-1

Status of the top quark forward backward asymmetry

However, the case for the $A_{FB}^{t\,\bar{t}}$ excess persisting is pretty strong.

Excitement sourced out of:



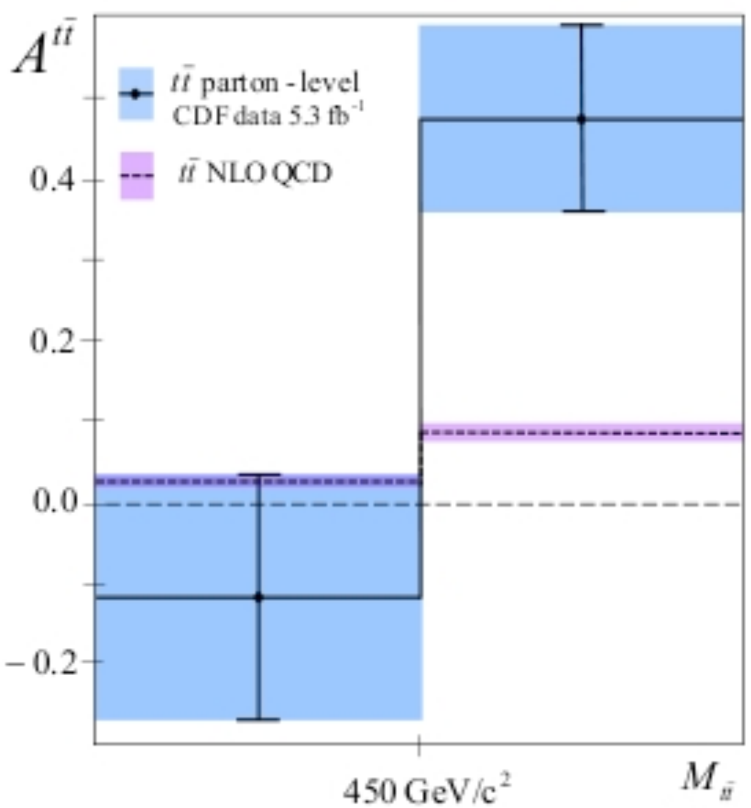
normalization by
NLO cross section.

Evidence for a Mass Dependent Forward-Backward Asymmetry in Top Quark Pair Production.

arXiv:1101.0034 - 188 citations!

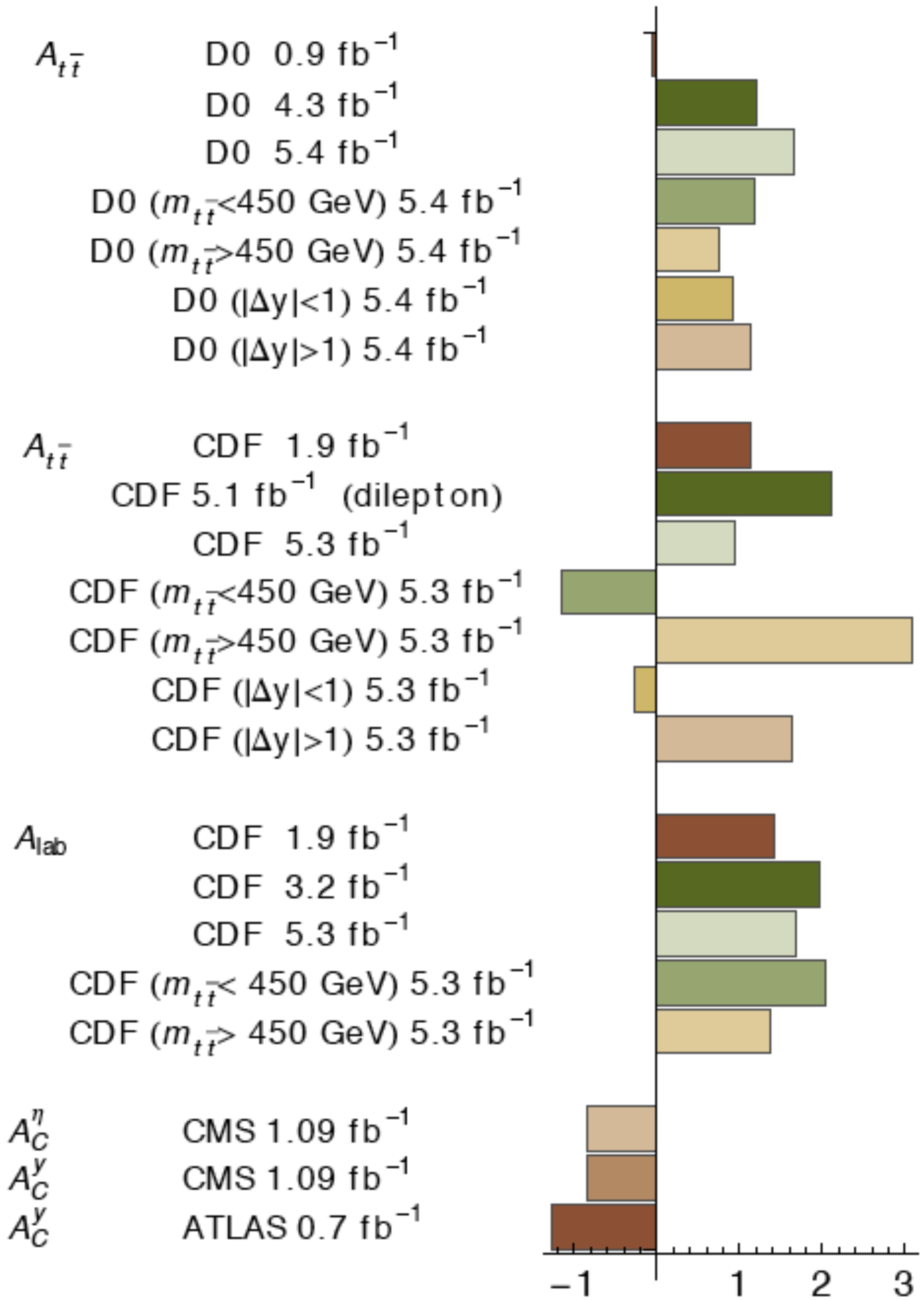
Status of the top quark forward backward asymmetry

Excitement sourced out of:



Kuhn & Rodrigo's 1109.6830

Do we have a problem?
(normalization by LO xsection)



Status of the top quark forward backward asymmetry

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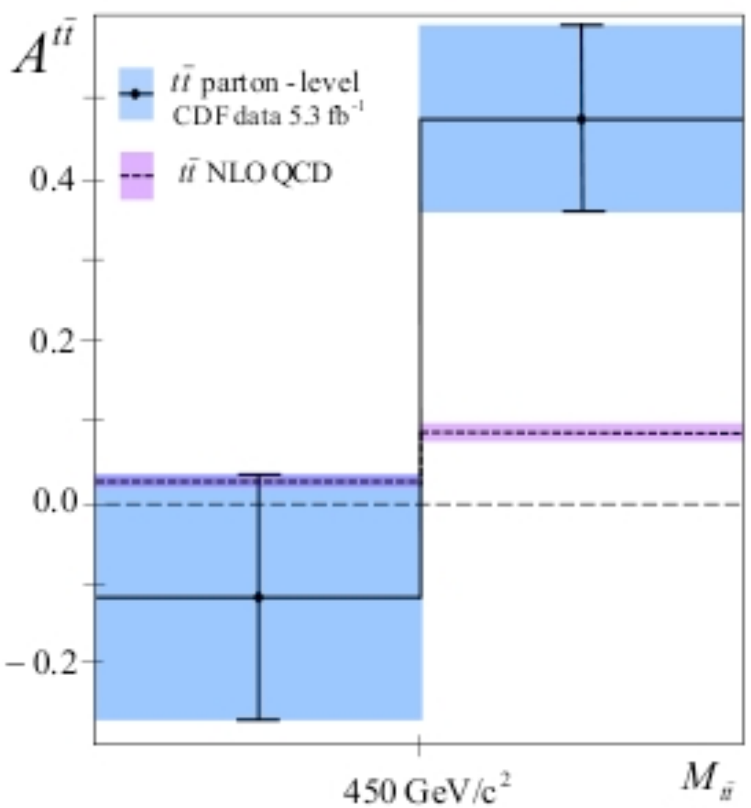
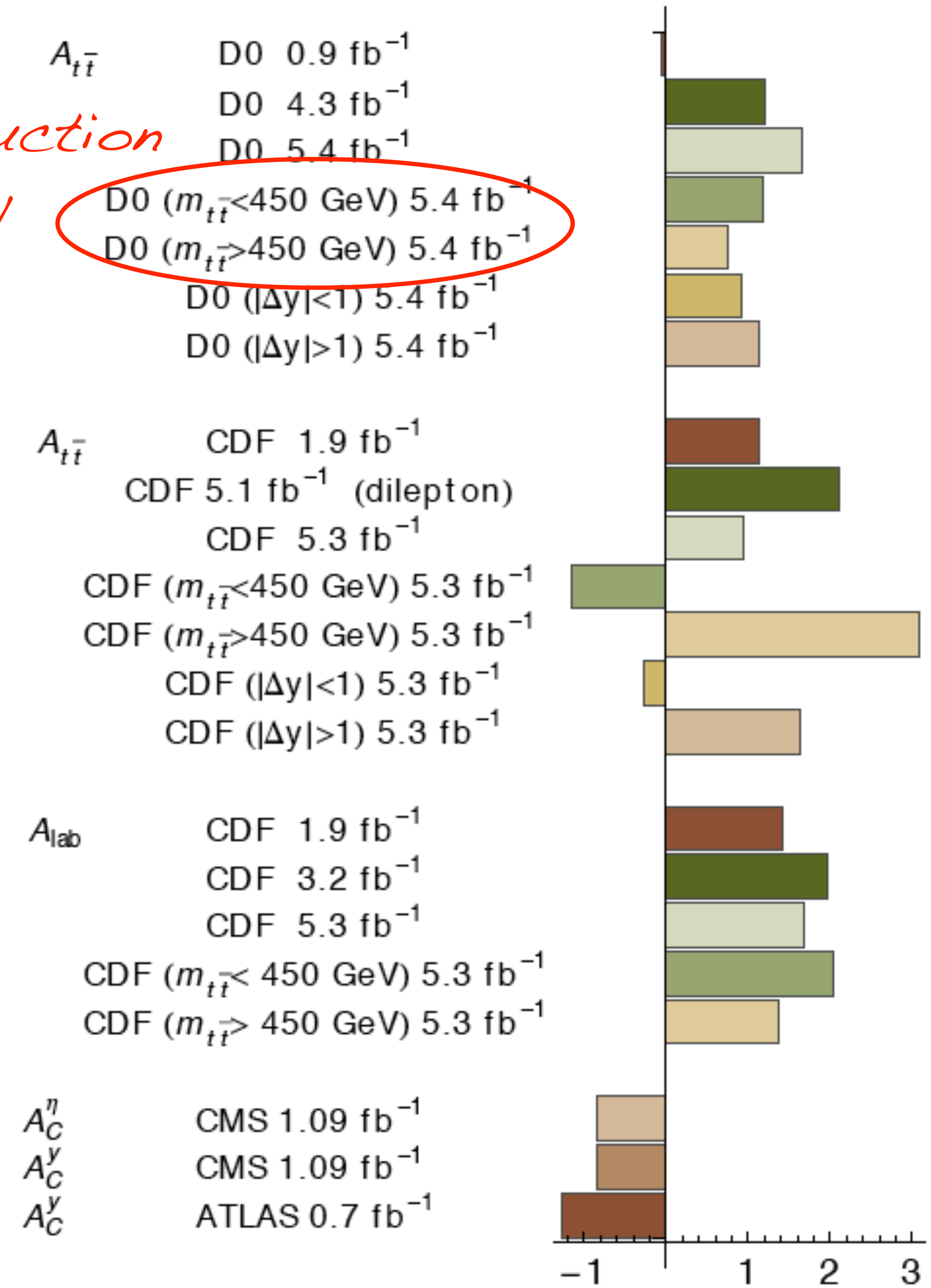


reconstruction level



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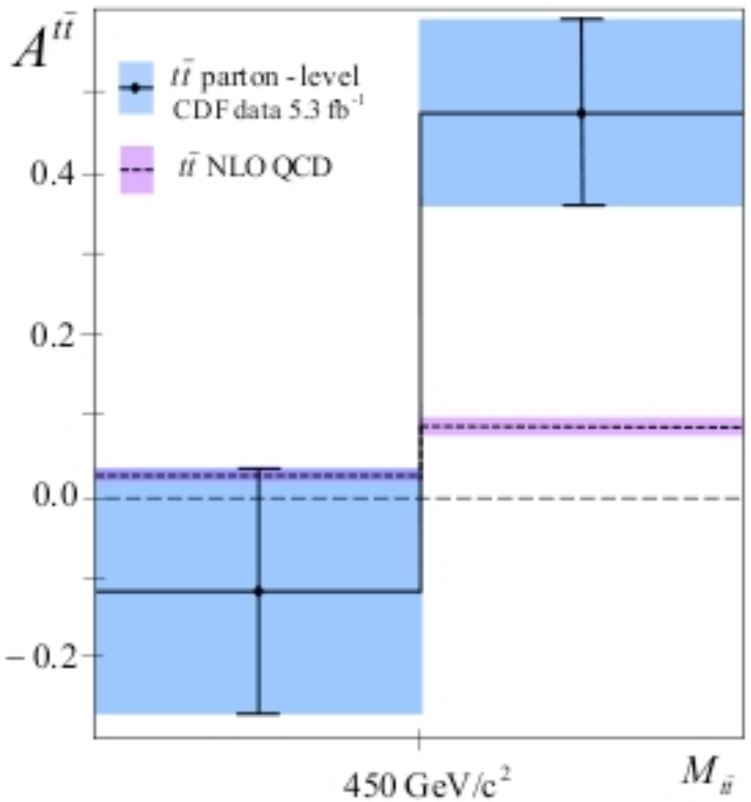
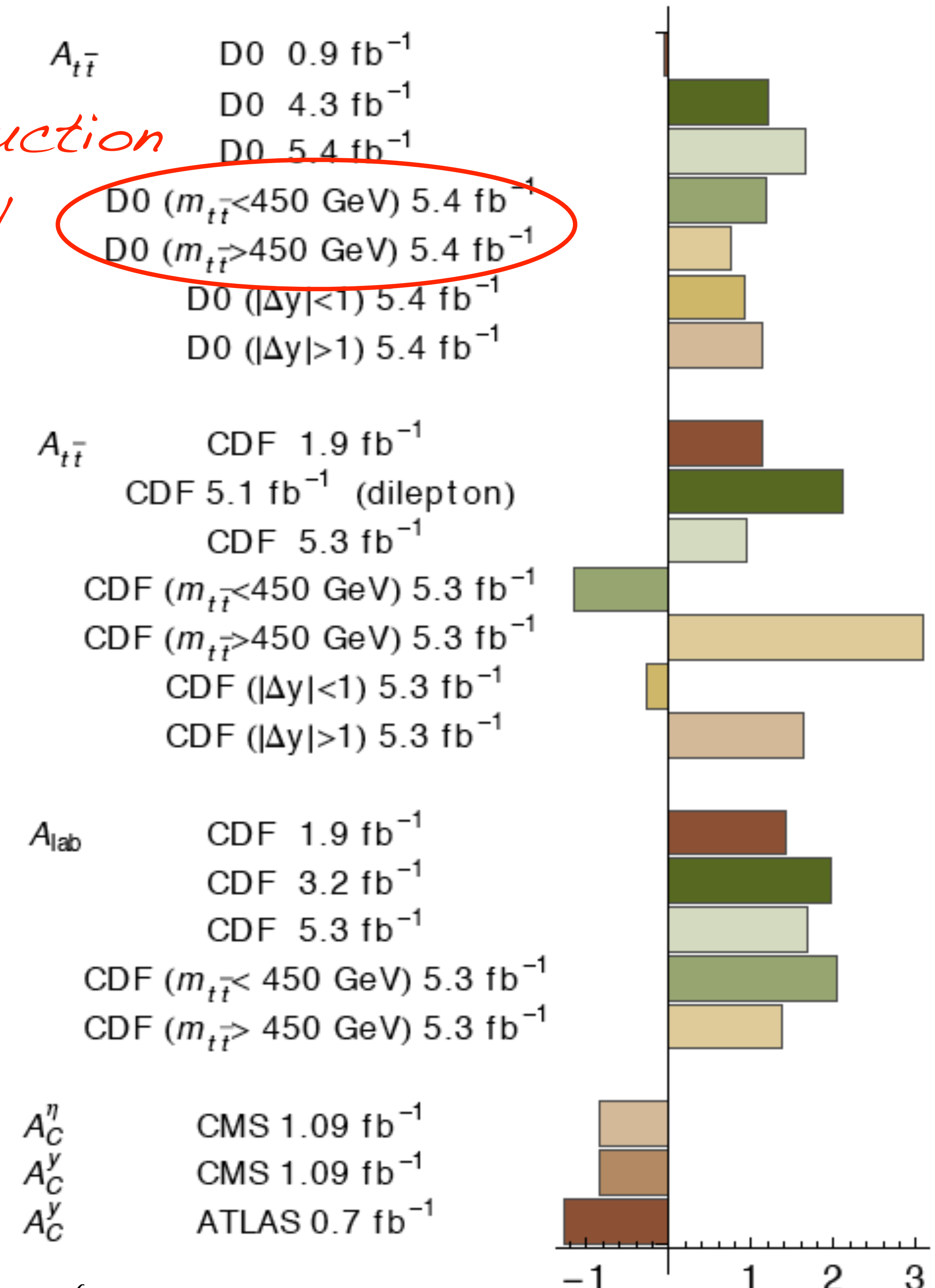
Status of the top quark forward backward asymmetry

Excitement sourced out of:



reconstruction level



reconstruction level A^ℓ D0 5.4 fb^-1

Status of the top quark forward backward asymmetry

Other recent data flow: 1.04 fb^-1 of data from T. Lari, INFN Milano, ATLAS at the
NPKI launching workshop: Top physics and electroweak symmetry breaking in the LHC era Feb 27,2011

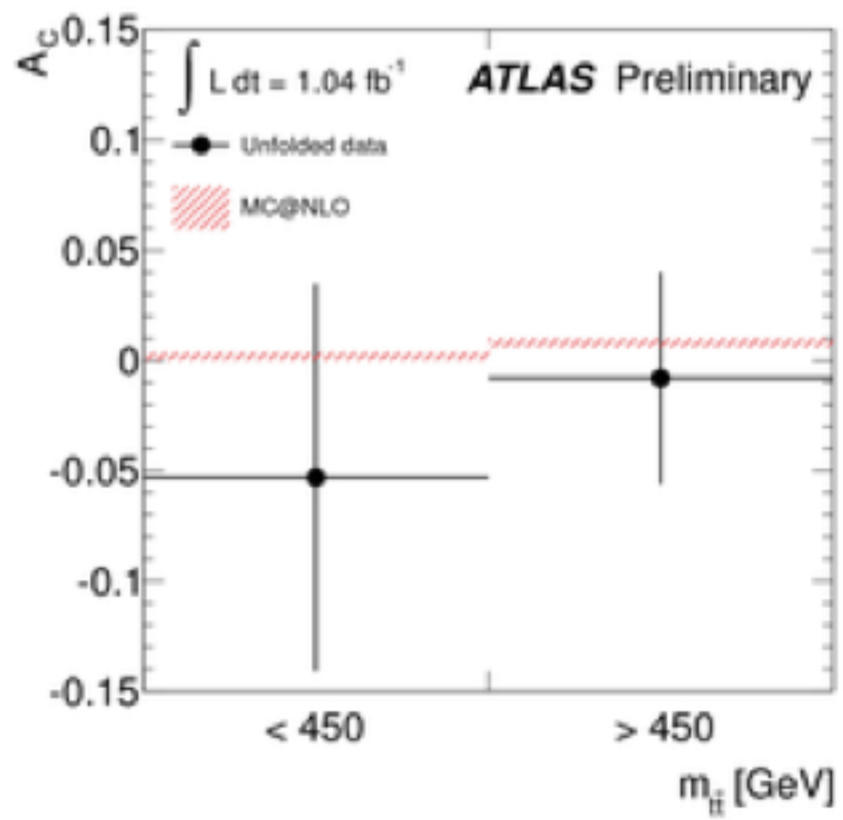
$$A_C = -0.018 \pm 0.028\ (\text{stat.}) \pm 0.023\ (\text{syst.})$$

and

$$A_C = -0.053 \pm 0.070\ (\text{stat.}) \pm 0.054\ (\text{syst.}) \quad \text{for } m_{t\bar{t}} < 450\ \text{GeV},$$

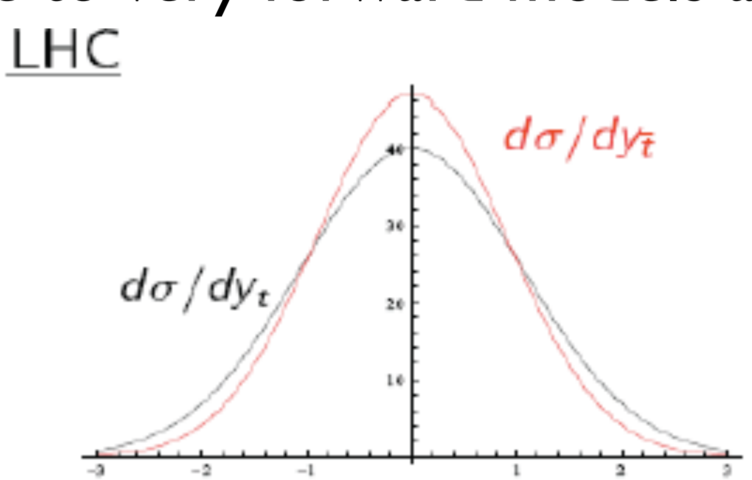
$$A_C = -0.008 \pm 0.035\ (\text{stat.}) \pm 0.032\ (\text{syst.}) \quad \text{for } m_{t\bar{t}} > 450\ \text{GeV}.$$

Atlas - pending paper.



Sensitive to very forward models as charge asymmetry measures rapidity spread.

Recall:



basic idea q from valance, antiq from sea.

q more boosted, t along q less central.

Need the SM ratio estimated as accurately as possible

What is state of the art?

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

Known to leading order: $\mathcal{O}(\alpha_s^3)$

First complete calc Kuhn&Rodrigo **hep-ph/9807420** building on Halzen et al, ($q\bar{q} \to Q\,\bar{Q}\,g$) and Berends et al for muon asym.

Known to NLO $\mathcal{O}(\alpha_s^3)$, also known is the effect of NLL and NNLL soft gluon resums on the total cross section

nason,dawson,ellis,beenaker,kuijf,neervan,sith,czakon,mitov,,manga no,ridolfi,moch,uwer,langenfeld,beneke,falgari,schwinn,aherns,ferro glia,neubert,pecjak,yang,kidonakis,cacciari, etc etc

Stand out state of the art now for inclusive total cross section based on NLO +NNLL resum:

- Czakon, Mitov, Sterman http://arXiv.org/abs/arXiv:0907.1790
- M. Beneke, P. Falgari and C. Schwinn, arXiv:0907.1443 [hep-ph].

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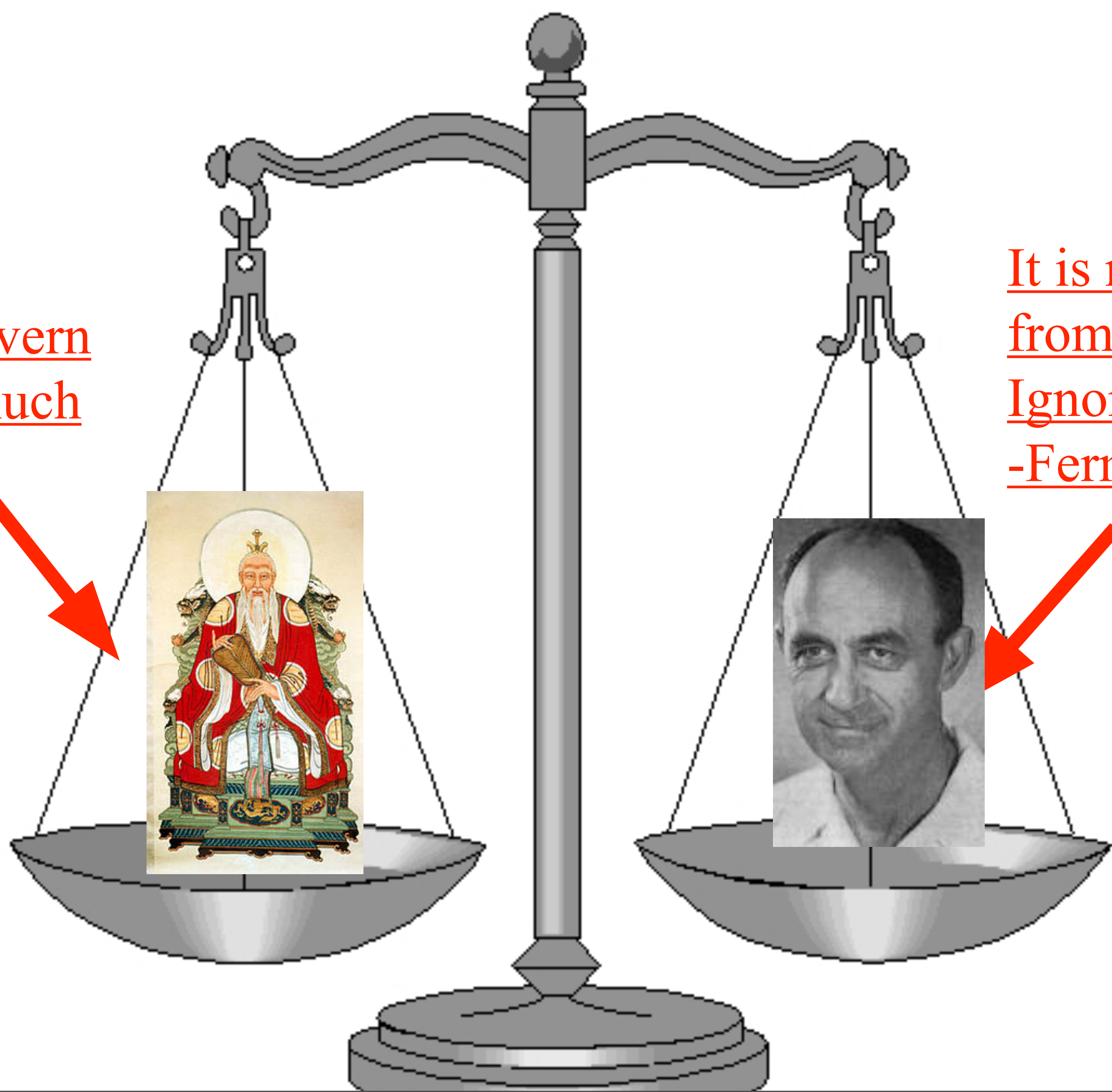
How should we normalize?
LO/LO or LO/NLO or LO/NLO+NNLL?

People are difficult to govern because they have too much knowledge. -**Lao-tzu**



It is no good to try to stop knowledge from going forward.
Ignorance is never better than knowledge.
-Fermi

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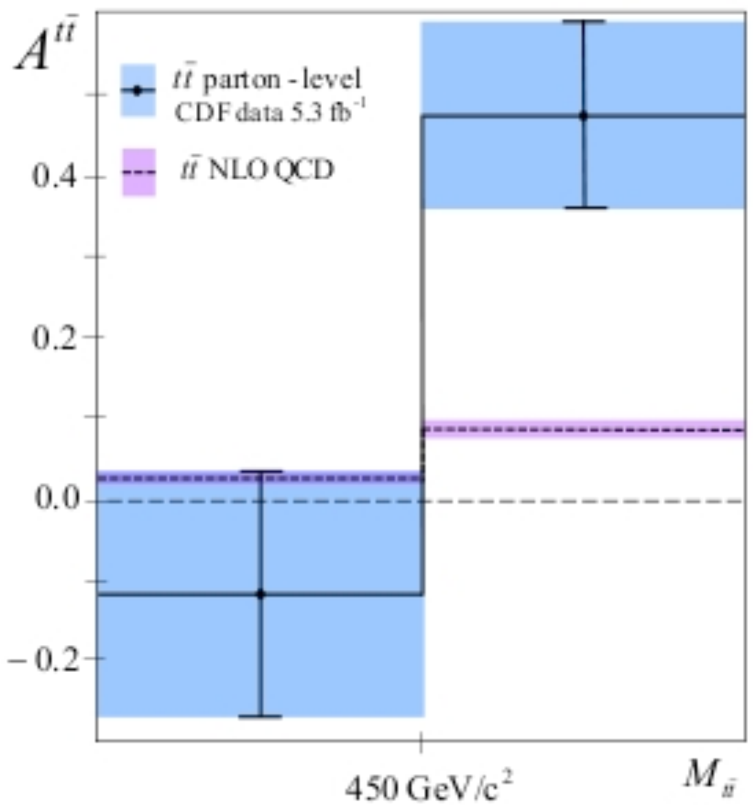
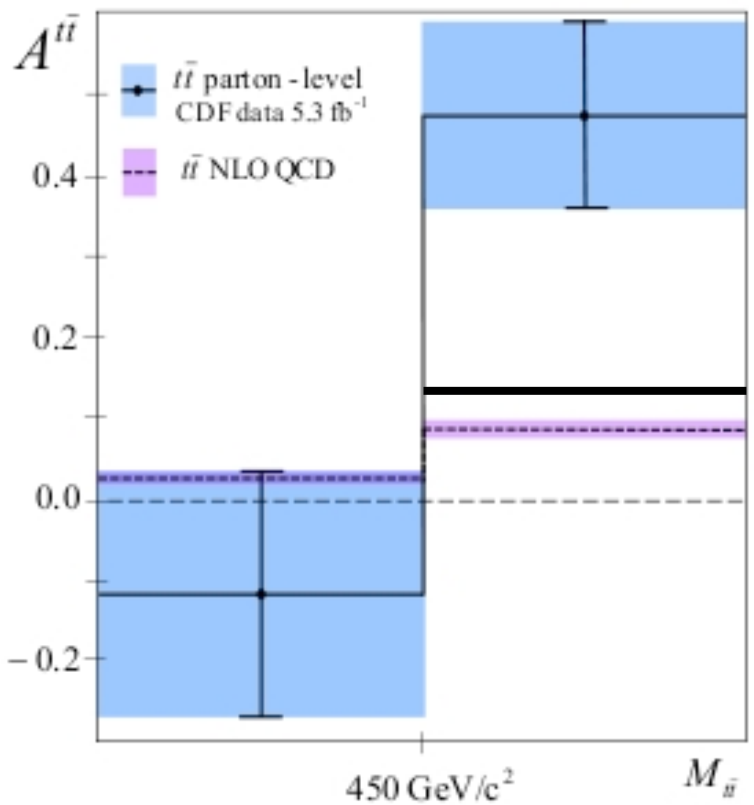
Norm makes a BIG difference:





Theory is moving

arXiv: 1201.3926
Manohar & Trott
latest number

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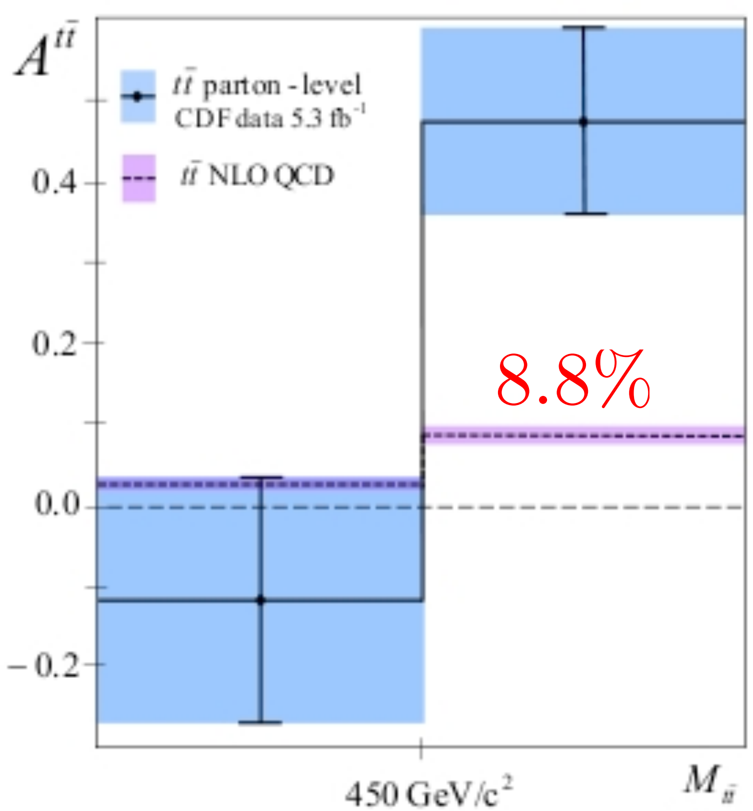
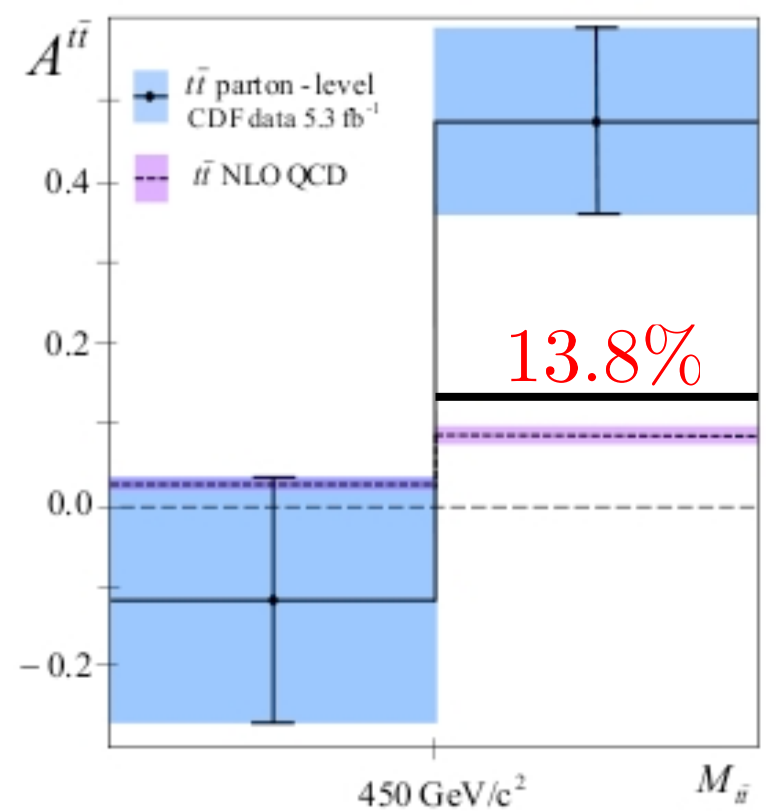




Theory is moving a bit-not enough

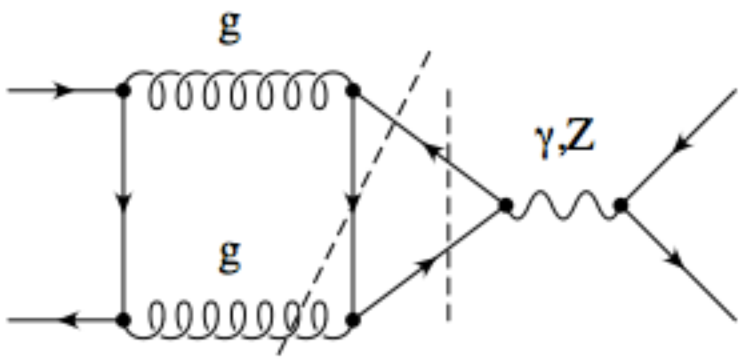
arXiv: 1201.3926 Manohar & Trott latest number

Changes - NLO vs NLO+NNLL norm, more fixed order EW, Sudakov

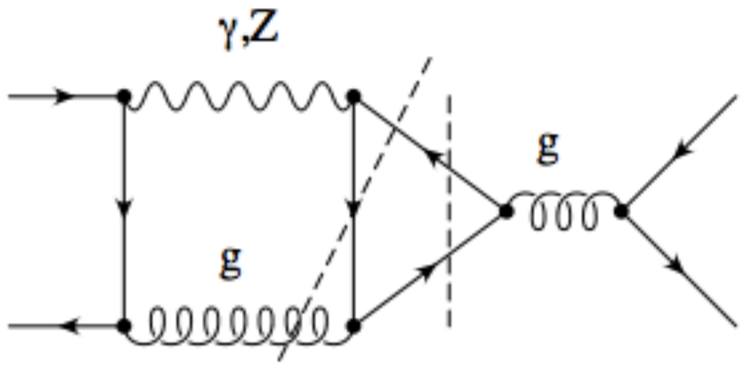
Recent Progress in the SM calc of $A_{FB}^{t\,t}$

Fixed order EW calculations have been refined:

Kuhn and Rodrigo **hep-ph/9807420, similar class of diagrams in fixed order EW: x 1.09 for EW**



(a)



(b)

and lots more....

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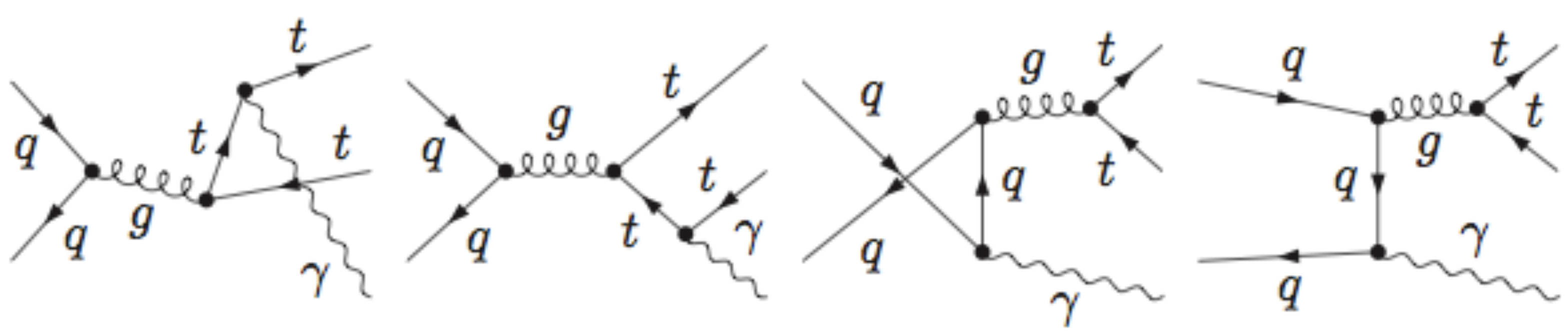
Holik and Pagini **hep-ph/1107.2606, more fixed order EW: x 1.22 for EW**



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MCFM number LO/NLO used by CDF (high bin): 8.8 ± 1.3

Ahrens,Ferroglia,Neubert,Pecjak,Yang
1106.6051 (high bin):

	$A_{\rm FB}^{t\bar{t}}[\%]$		
	$47.5^{+11.2}_{-11.2}$		
	MSTW	CTEQ	NNPDF
NLO	$10.8^{+1.0}_{-0.8}$	$10.4^{+1.0}_{-0.6}$	$10.9^{+0.7}_{-0.6}$
NLO+NNLL	$11.1^{+1.7}_{-0.9}$	$10.8^{+1.7}_{-0.9}$	$11.4^{+1.3}_{-1.0}$

Pagini Holik 1107.2606 LO/LO + EW (high bin): 12.77

Kuhn/Rodrigo 1109.6830 LO/LO + EW (high bin): 12.8 ± 1.1

Recent Progress in the SM calc of $A_{FB}^{t\,t}$

Fixed order EW calculations have been refined:

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MCFM number LO/NLO used by CDF (high bin): 8.8 ± 1.3

Manohar and Trott **arXiv:1201.3926** (high bin):

Bin [GeV]	$A_{\mathrm{FB}}^{t\bar{t}}(\%)$		
$[2\,m_{t\bar{t}}, 1960]$	7.7	7.5	1.6
$[2\,m_{t\bar{t}}, 450]$	5.6	5.4	–
$[450, 900]$	11	12	2.3

LO/LO + EWS

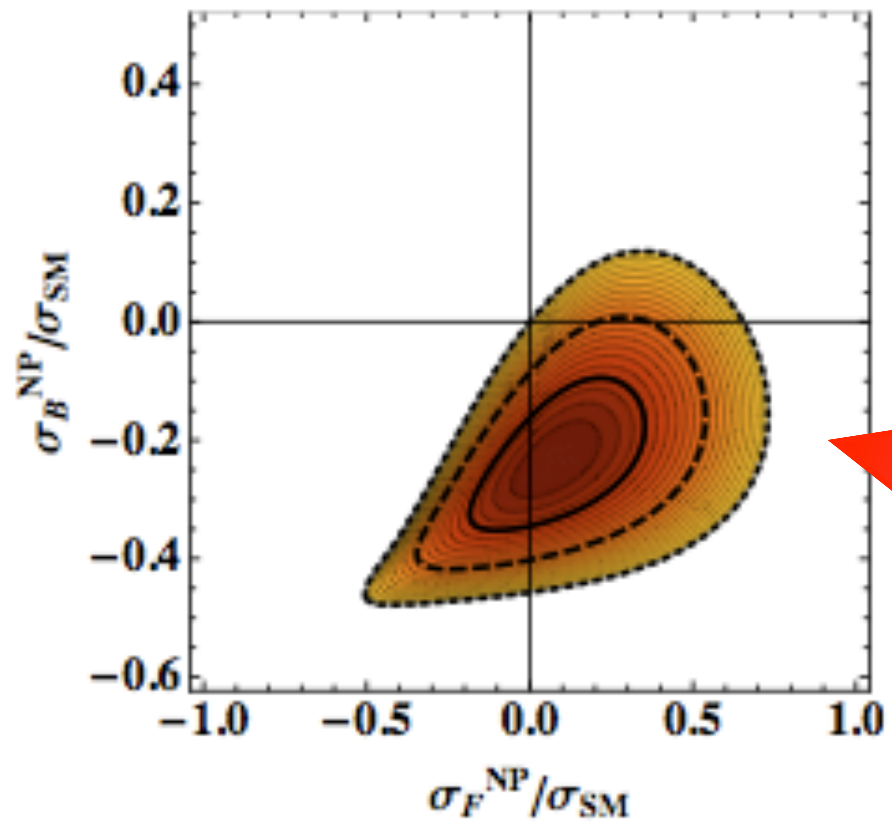
LO/NLO+NNLL(Neubert group) + EWS

FO EW to add
(~0.5 double count)

Status of the top quark forward backward asymmetry

The bottom line: $$A_{FB}^{t\bar{t}} = \frac{\sigma_F^{SM} - \sigma_B^{SM} + \sigma_F^{NP} - \sigma_B^{NP}}{\sigma_F^{SM} + \sigma_B^{SM} + \sigma_F^{NP} + \sigma_B^{NP}},$$

NP-SM interference + NP^2 can be either sign.



Smoking gun for new physics interference?

arXiv: 1102.3374 – Phys.Rev.Lett.107:012002,2011.

Grinstein, Kagan, Trott, Zupan

Status of the top quark forward backward asymmetry

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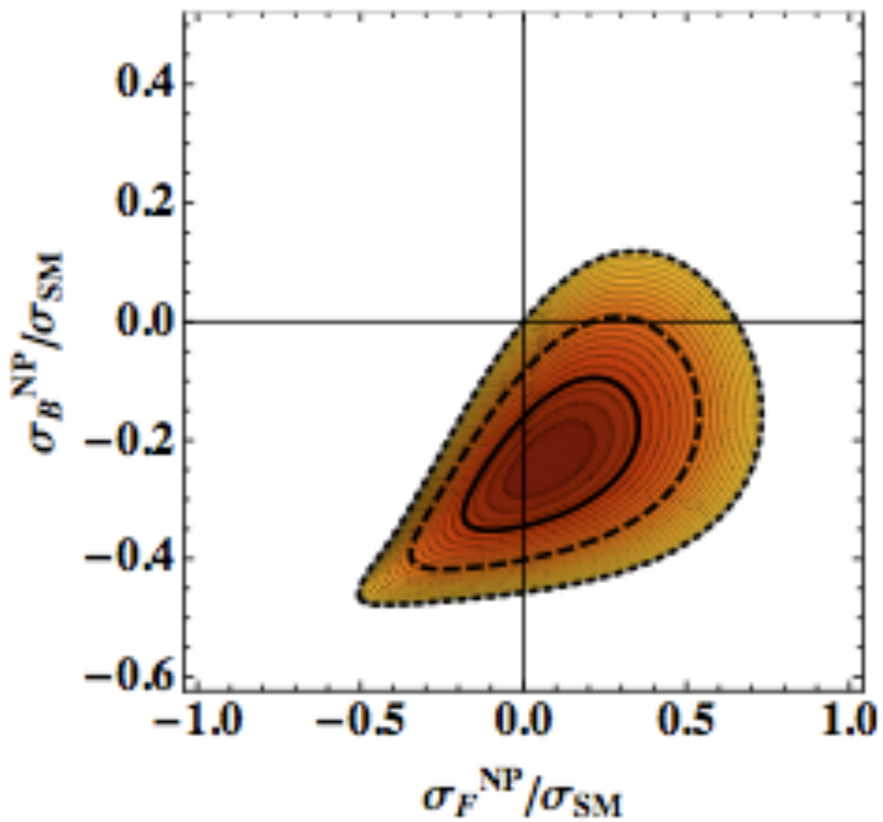

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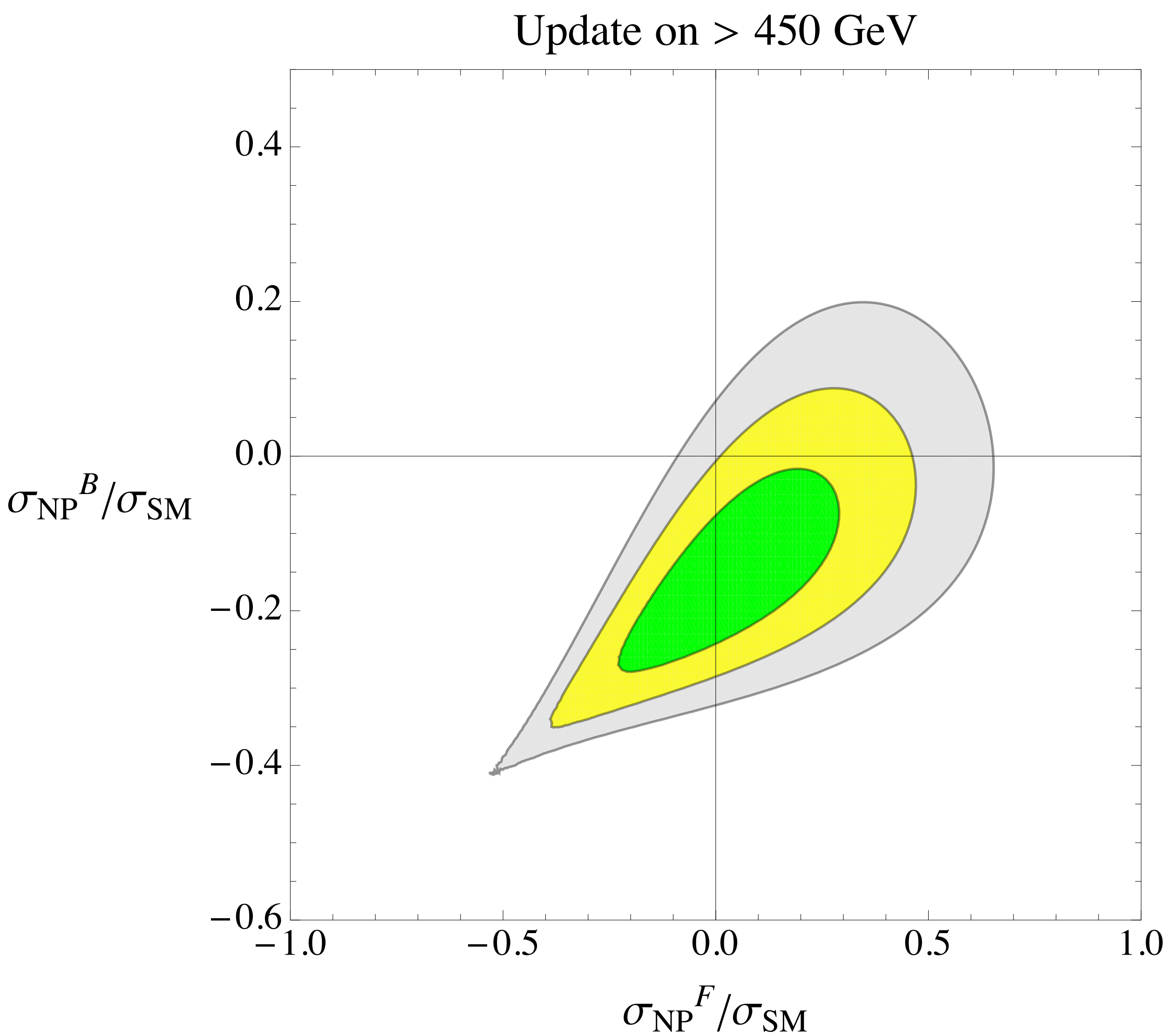


update with the discussed modifications.

EW Sudakovs and $A_{FB}^{t\,\bar{t}}$

Manohar and Trott **arXiv:1201.3926, Sum LL, NLL, class of NNLL EW Sudakovs: x 1.05 for SM EW**

Sum terms of form: $(\alpha/\sin^2\theta_W)^n\ \log^{m\leq 2n}(s/M_{W,Z}^2)$
these logs appear in the fixed order EW expansions order by order and are big!

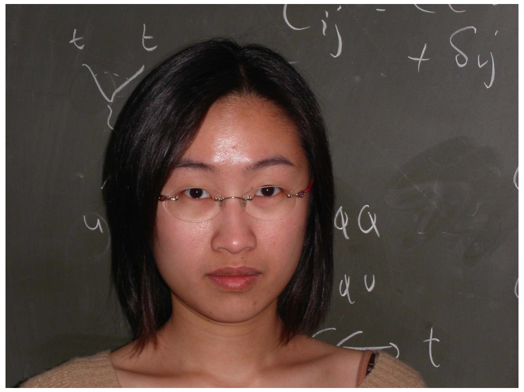
EW Sudakovs and $A_{FB}^{t\bar{t}}$

Manohar and Trott **arXiv:1201.3926, Sum LL, NLL, class of NNLL EW Sudakovs: x 1.05 for SM EW**

$$L = \log\left(\frac{s}{m_{W,Z}^2}\right) \qquad \mathfrak{M} = \begin{pmatrix} 1 & & & & \\ \alpha L^2 & \alpha L & \alpha & & \\ \alpha^2 L^4 & \alpha^2 L^3 & \alpha^2 L^2 & \alpha^2 L & \alpha^2 \\ \alpha^3 L^6 & & \dots & & \\ \vdots & & & & \end{pmatrix}$$

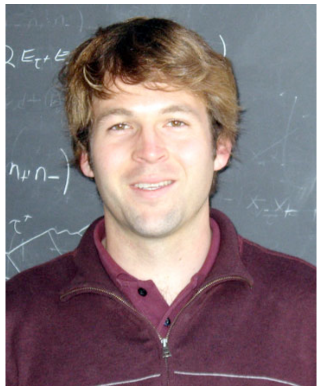
order by order in fixed order calculations

Formalism used here for SM EWS (EW Sudakov) corrections developed by:



Chiu

Fuhrer



Kelley

Manohar

and Golf.

in arXiv:0709.2377, arXiv:0712.0396, arXiv:0806.1240,arXiv:0905.1141, arXiv:0901.1332, arXiv:0909.0947,arXiv:1003.0025, arXiv:1011.1505

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$$L = \log\left(\frac{s}{m_{W,Z}^2}\right) \qquad \mathfrak{M} = \begin{pmatrix} 1 & & & & \\ \boxed{\begin{matrix} \alpha \mathsf{L}^2 \\ \alpha^2 \mathsf{L}^4 \\ \alpha^3 \mathsf{L}^6 \\ \vdots \end{matrix}} & \begin{matrix} \alpha \mathsf{L} \\ \alpha^2 \mathsf{L}^3 \\ \\ \\ \end{matrix} & \begin{matrix} \alpha \\ \alpha^2 \mathsf{L}^2 \\ \cdots \\ \\ \end{matrix} & \begin{matrix} \\ \alpha^2 \mathsf{L} \\ \\ \\ \end{matrix} & \begin{matrix} \\ \alpha^2 \\ \\ \\ \end{matrix} \end{pmatrix}$$

order by order in fixed
order calculations

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order by order in fixed order calculations

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order by order in fixed order calculations

Missing: higgs effects in three loop cusp anom dimension + a 2 loop matching.

EW Sudakovs and $A_{FB}^{t\,\bar{t}}$

Manohar and Trott **arXiv:1201.3926, Sum LL, NLL, class of NNLL EW Sudakovs: x 1.05 for SM EW**

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order by order in fixed order calculations

Some overlap with fixed order EW calculations, which we estimate to be ~0.5%

NOT the same as fixed order! (but can be combined)

As we head out to larger $\sqrt{s}$, resums of these terms are absolutely required.

It turns out that for ratios like $A_{FB}^{t\,\bar{t}}$ - there is a smaller EWS correction due to a partial cancelation.

EW Sudakovs and $A_{FB}^{t\bar{t}}$

Sum LL, NLL, class of NNLL EW Sudakovs: x 1.05 for SM EW

All that work and theory technology for a 5% effect?

EW Sudakovs and $A_{FB}^{t\bar{t}}$

Sum LL, NLL, class of NNLL EW Sudakovs: x 1.05 for SM EW

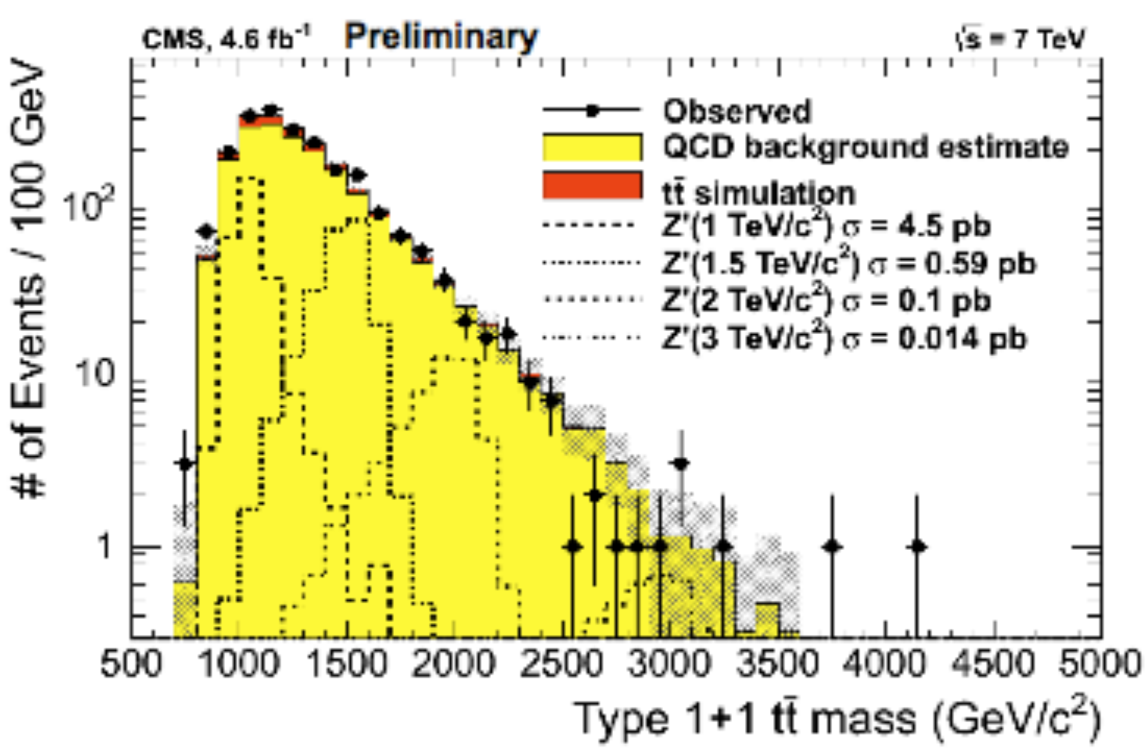
All that work and theory technology for a 5% effect?

EW Sudakovs and $A_{FB}^{t\,\bar{t}}$

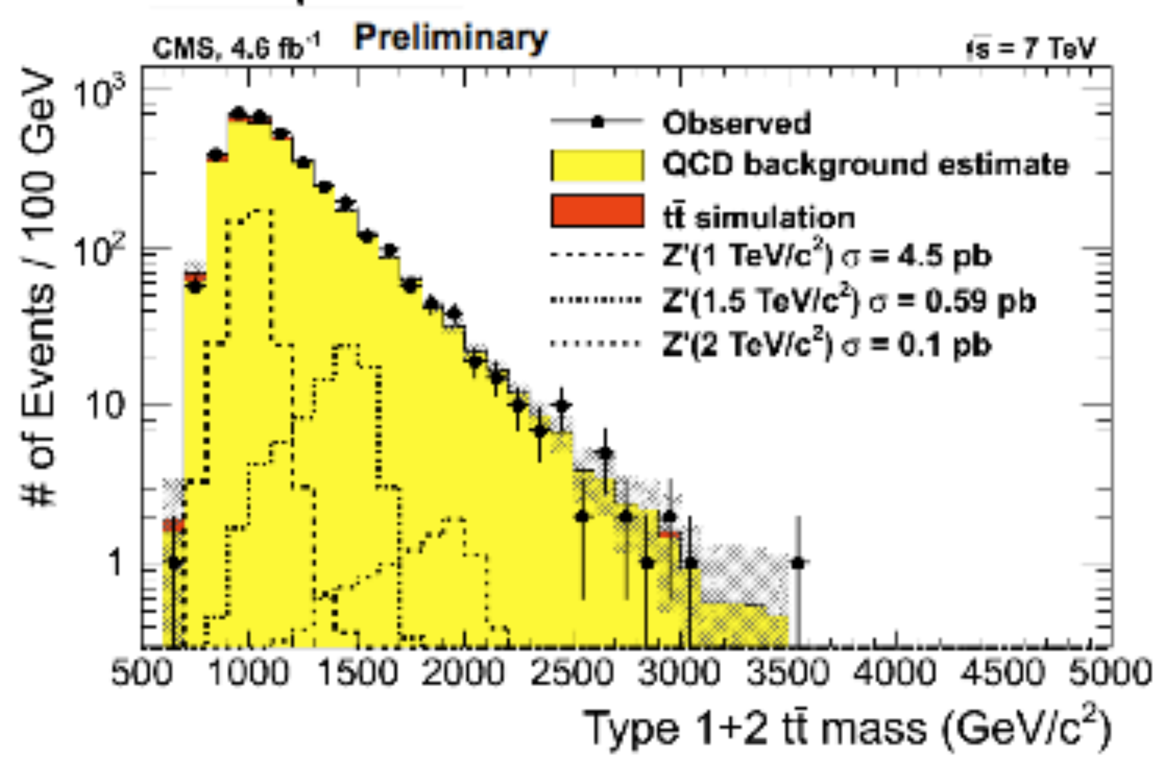
If this is NP, where else should we see it? $\dfrac{d\,\sigma^{t\,\bar{t}}}{d\,M_{t\,\bar{t}}}$ & $\dfrac{d\,\sigma^{JJ}}{d\,M_{JJ}}$

At large invariant mass you should see something.

Type 1+1 mass



Type 1+2 mass



latest from CMS - **Eva Halkiadakis Jan 31 CERN** CMS PAS-EXO-11-006

EW Sudakovs and $A_{FB}^{t\bar{t}}$ & $\dfrac{d\,\sigma^{t\bar{t}}}{d\,M_{t\bar{t}}}$ & $\dfrac{d\,\sigma^{JJ}}{d\,M_{JJ}}$

At large invariant mass you should see something in the ttbar spec.

Defining simple correction factors to put in the EWS's (exponential corrections):

$$\mathcal{R}_t = \frac{\sigma_{t\bar{t}}^{QCD+EWS}}{\sigma_{t\bar{t}}^{QCD}}$$

Corrections for LHC7/14 production are given by:

If these SM corrections are neglected then one could CANCEL the effect of NP on this spectrum.

Bin [GeV]	$\mathcal{R}_t$	
[50, 3000]	–	–
[350, 3000]	0.97	0.97
[50, 250]	–	–
[250, 500]	–	–
[350, 500]	0.98	0.98
[500, 750]	0.97	0.97
[750, 1000]	0.95	0.95
[1000, 1500]	0.94	0.94
[1500, 2000]	0.92	0.92
[2000, 2500]	0.90	0.91
[2500, 3000]	0.88	0.89
[3000, 3500]	0.87	0.88
	7 TeV	14 TeV

arXiv: 1201.3926
Manohar & Trott

EW Sudakovs and $A_{FB}^{t\bar{t}}$ & $\frac{d\sigma^{t\bar{t}}}{dM_{t\bar{t}}}$ & $\frac{d\sigma^{JJ}}{dM_{JJ}}$

At large invariant mass you should see something in dijets.

We calculated the EWS corrections for all $2 \to 2$ processes in QCD

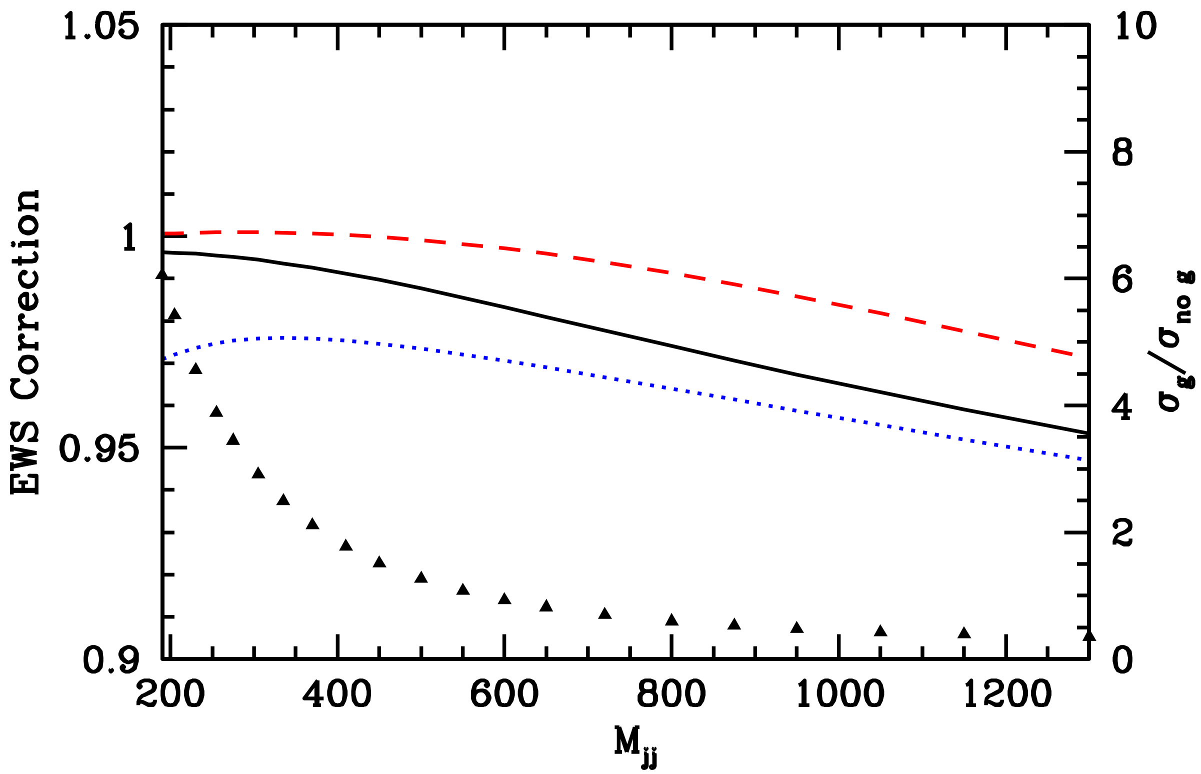
From QCD and Collider physics
Ellis, Stirling, Weber

If these SM corrections are neglected then one could CANCEL the effect of NP on this spectrum.

Process	$\sum\lvert\mathcal{M}\rvert^2/g^4$
$q\,q' \to q\,q'$	$\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$
$q\,\bar{q}' \to q\,\bar{q}'$	$\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$
$q\,q \to q\,q$	$\frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2}\right)-\frac{8}{27}\frac{\hat{s}^2}{\hat{u}\hat{t}}$
$q\,\bar{q} \to q'\,\bar{q}'$	$\frac{4}{9}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}$
$q\,\bar{q} \to q\,\bar{q}$	$\frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right)-\frac{8}{27}\frac{\hat{u}^2}{\hat{s}\hat{t}}$
$q\,\bar{q} \to g\,g$	$\frac{32}{27}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}}-\frac{8}{3}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}$
$g\,g \to q\,\bar{q}$	$\frac{1}{6}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}}-\frac{3}{8}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}$
$g\,q \to g\,q$	$-\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{s}\hat{u}}+\frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2}$
$g\,g \to g\,g$	$\frac{9}{2}\left(3-\frac{\hat{t}\hat{u}}{\hat{s}^2}-\frac{\hat{s}\hat{u}}{\hat{t}^2}-\frac{\hat{s}\hat{t}}{\hat{u}^2}\right)$

EW Sudakovs and $A_{FB}^{t\,\bar{t}}$ & $\frac{d\,\sigma^{t\,\bar{t}}}{d\,M_{t\,\bar{t}}}$ & $\frac{d\,\sigma^{JJ}}{d\,M_{JJ}}$

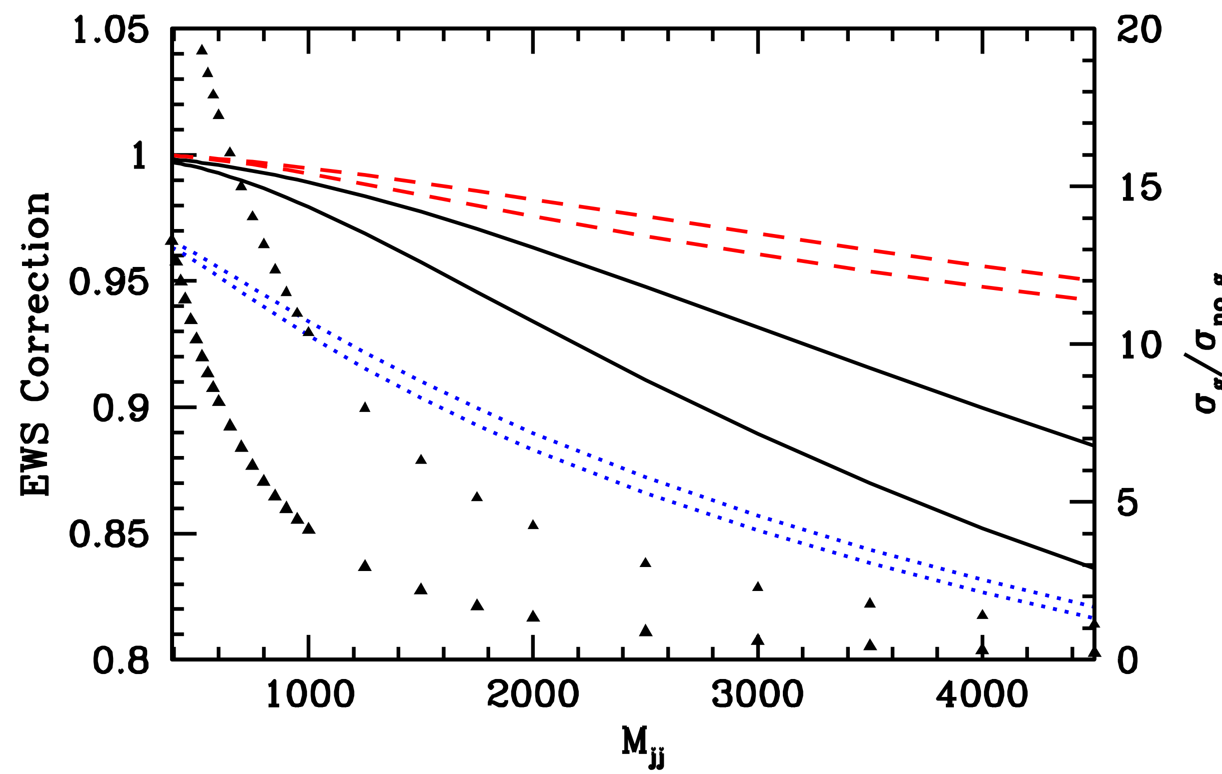
Correction factor for LL + NLL + NNLL SM EW Sudakovs



LHC7/14 EWS correction to dijet invariant mass

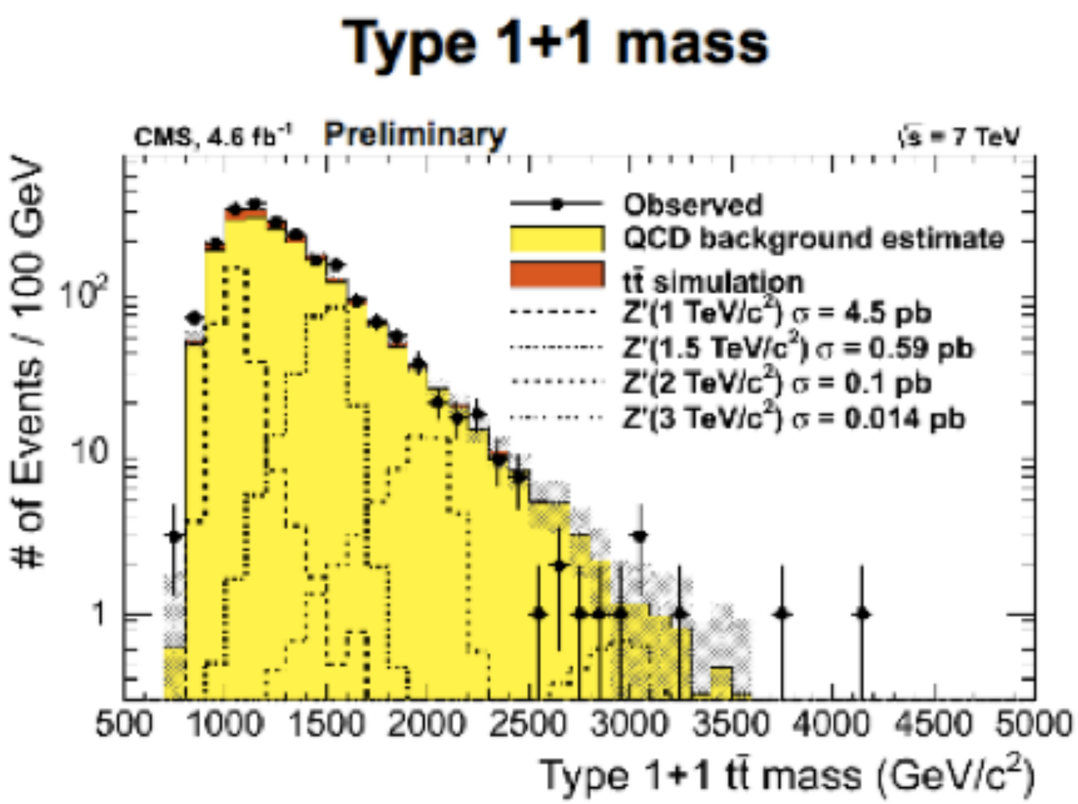
Tevatron EWS correction to dijet invariant mass spectrum

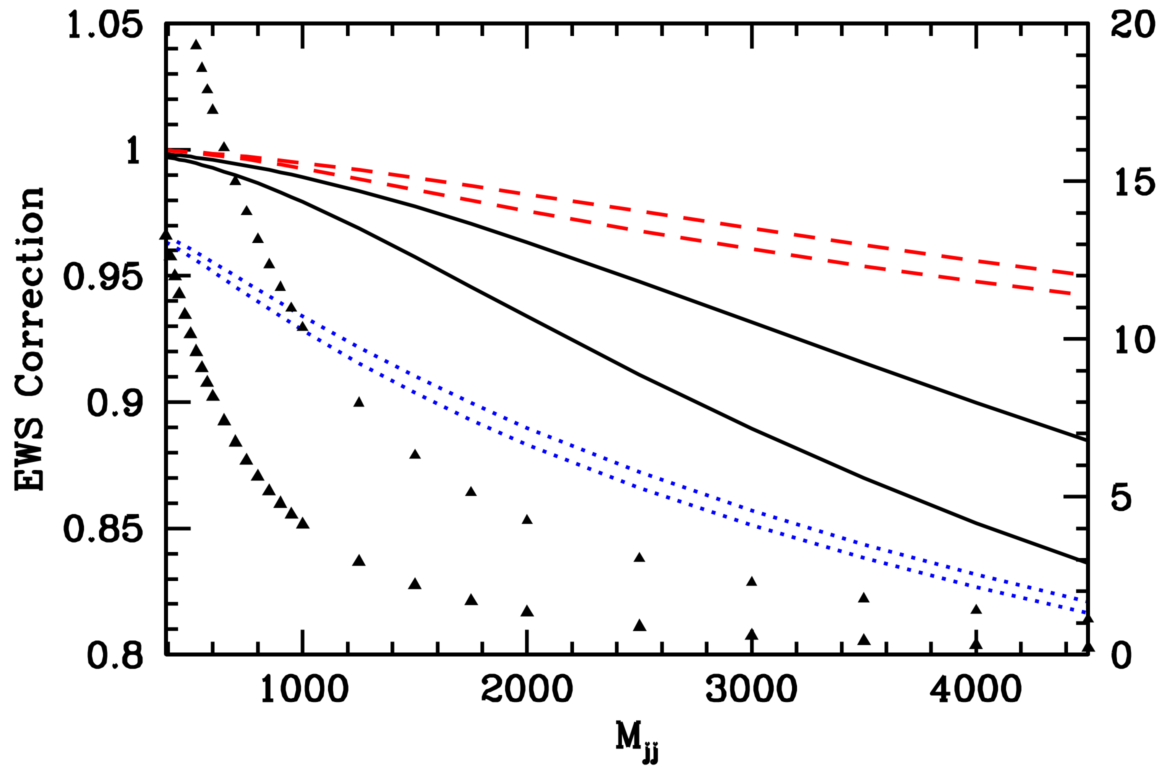
arXiv: 1201.3926
Manohar & Trott



EW Sudakovs - neglect at your peril!

The effects go in the same direction and combined impact is even bigger.





[750, 1000]	0.95
[1000, 1500]	0.94
[1500, 2000]	0.92
[2000, 2500]	0.90
[2500, 3000]	0.88
[3000, 3500]	0.87

arXiv: 1201.3926
Manohar & Trott

10-20% correction to giant subtracted dijet background AND the ttbar signal

EW Sudakovs

DISCLAIMER?

What about real emission? Good question.

More inclusive observables usually have sudakov effects cancelling against real emission. There is a theorem!
In non-abelian theories if you can (have to) distinguish the initial and final states in the multiplet you get bloch-nordsieck violation.

Pdf's matter. Even if the final state is inclusive -the initial flavour weight is a weighted broken sum.

More needs to be done to add in other EW, the sudakov effect is this order though - there is a suppression of the tail.

Flavour Symmetric Models

In the SM, there is a well defined sense in which flavour symmetry is restored.

$$\mathcal{L}_{SM} = \mathcal{L}_{SM}^{G_F} + \underbrace{g_u^{ij}}_{\to 0} \, \bar{u}_R^i \, H^T \, \epsilon \, Q_L^j - \underbrace{g_d^{ij}}_{\to 0} \, \bar{d}_R^i \, H^\dagger \, Q_L^j + h.c.$$

Technically you can think of the Yukawas as symmetry breaking spurions:

$$g_u^{ij} \sim (3, 1, \bar{3}) \quad g_d^{ij} \sim (1, 3, \bar{3})$$

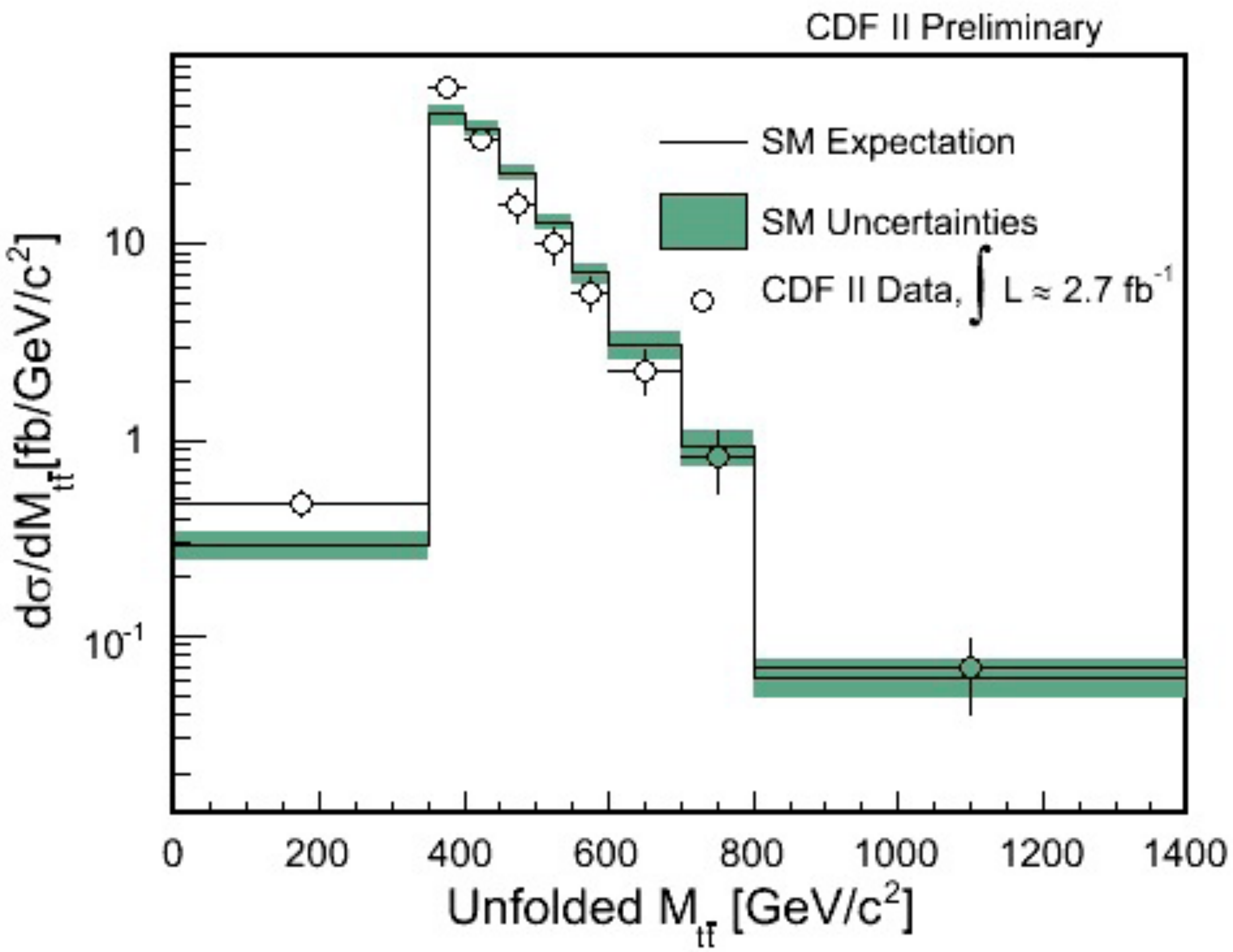
NO CLEAR EVIDENCE FOR OTHER SOURCES OF FLAVOUR VIOLATION.
Reach of flavour physics such that what we can find at LHC is strongly flavour constrained.

Paradigm 1: Hierarchy problem to model. Then tune your model to deal with constraints. Fine & depressing.

Paradigm 2: Start from a flavour symmetric point. Do EFT.

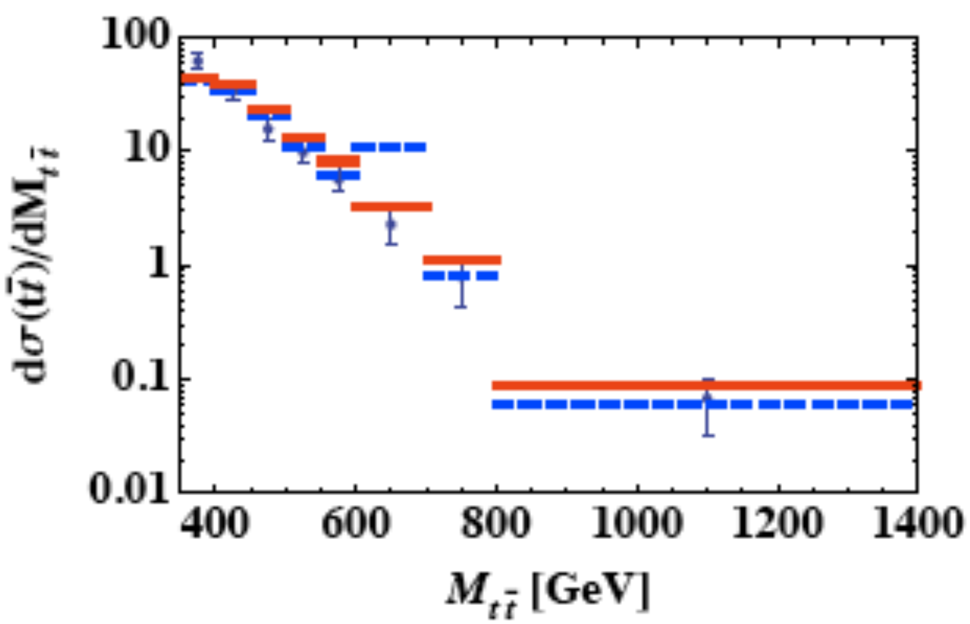
Flavour Symmetric Models

S -channel interference with a gluon exchange has to be a vector, colour octet. A massive vector octet in the S-channel is problematic



Measurement **arXiv:0903.2850 CDF collaboration** $2.7 fb^{-1}$

Large s channel resonance feature missing.



Typical s channel effect, width dictated by decay of vector field to quarks.

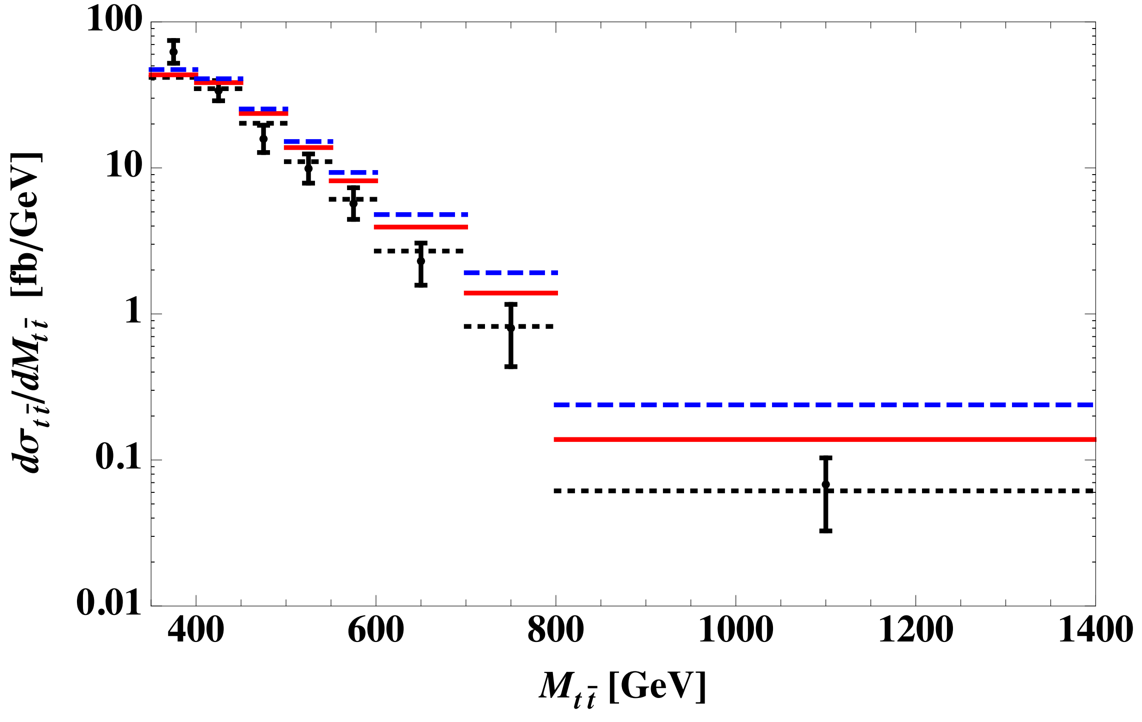
arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

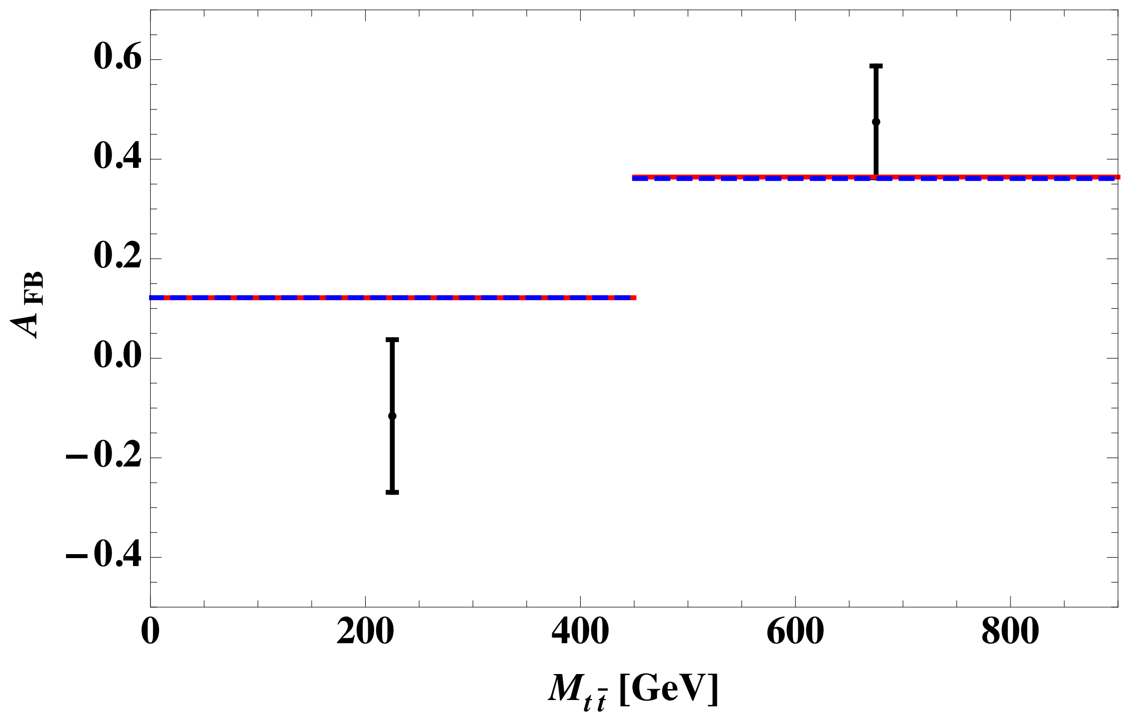
t -channel interference, or s and t channel requires flavour safe off diagonal couplings. Favour symmetric fields can do this.

Flavour Symmetric Models

Interesting flavour symmetric field ex: Vector $(8,1)_0$ and $(8,1,1)$ under $\mathrm{G_F}$

This field is interesting as it has s and t channel contributions to $A_{FB}^{t\bar{t}}$





Parameter choices $(M, \sqrt{\eta_{ij}\eta_{33}}, \eta_{i3}, \Gamma_V/M)$ of: $(300, 1, 1.33, 0.08)$

$(1200, 2.2, 4.88, 0.5)$

1102.3374 arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

Flavour Symmetric Models

Interesting flavour symmetric field ex: Vector $(8,1)_0$ and $(8,1,1)$ under $\mathrm{G_F}$

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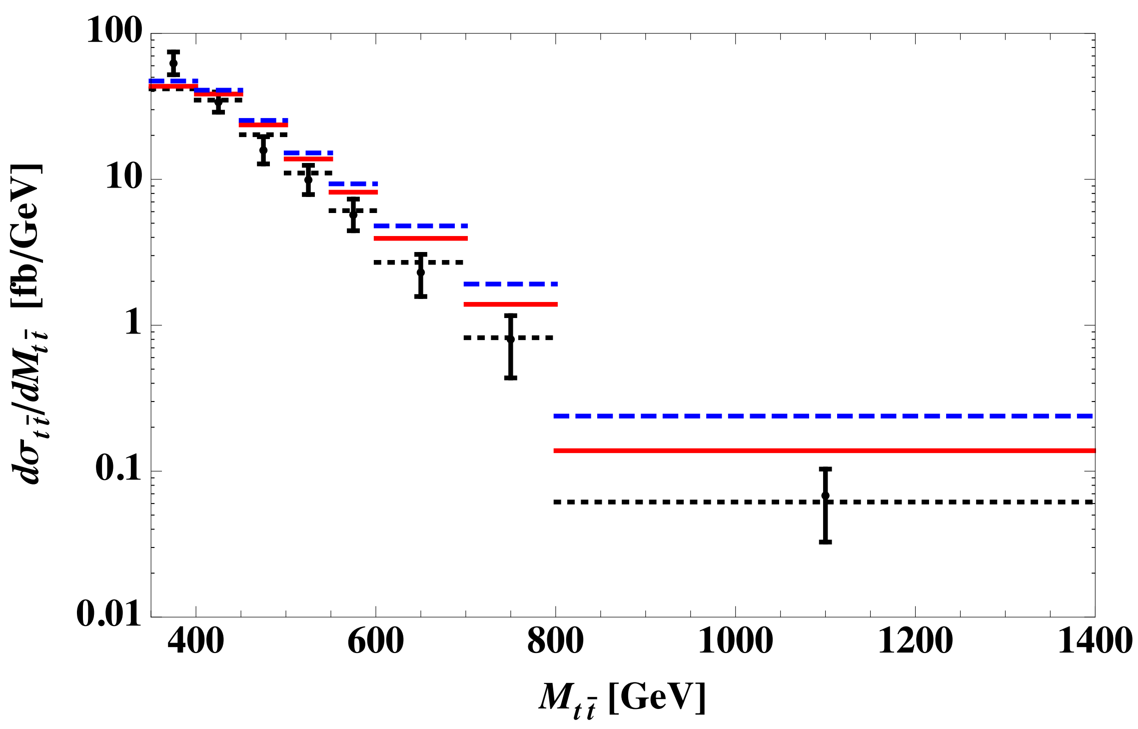
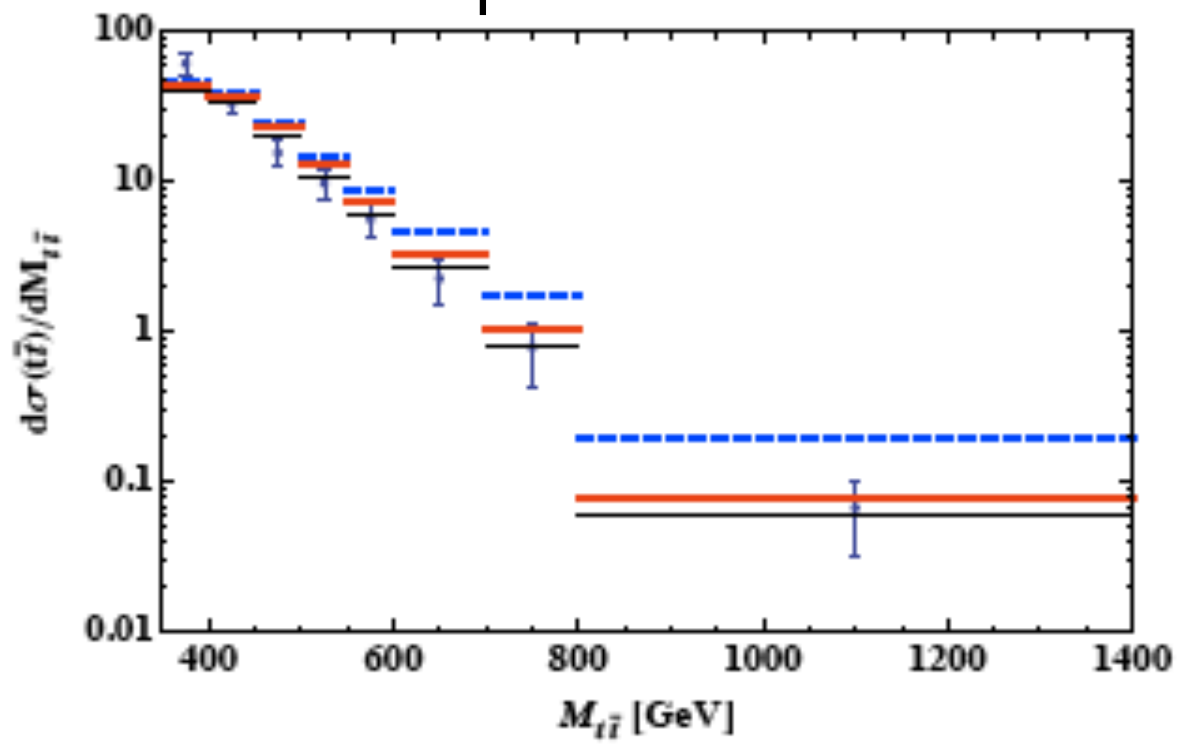


With acceptance corrections - better!



Parameter choices $(M, \sqrt{\eta_{ij}\eta_{33}}, \eta_{i3}, \Gamma_V/M)$ of: $(300, 1, 1.33, 0.08)$

$(1200, 2.2, 4.88, 0.5)$

1102.3374 arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

Here are 21 Flavour Symmetric options

(That are not flavour singlets.)

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
$I_{s,o}$	1,8	1	0	(1,1,1)	$\bar{d}_R \gamma^\mu d_R$
$II_{s,o}$	1,8	1	0	(1,1,1)	$\bar{u}_R \gamma^\mu u_R$
$III_{s,o}$	1,8	1	0	(1,1,1)	$\bar{Q}_L \gamma^\mu Q_L$
$IV_{s,o}$	1,8	3	0	(1,1,1)	$\bar{Q}_L \gamma^\mu Q_L$
$V_{s,o}$	1,8	1	0	(1,8,1)	$\bar{d}_R \gamma^\mu d_R$
$VI_{s,o}$	1,8	1	0	(8,1,1)	$\bar{u}_R \gamma^\mu u_R$
$VII_{s,o}$	1,8	1	-1	$(\bar{3},3,1)$	$\bar{d}_R \gamma^\mu u_R$
$VIII_{s,o}$	1,8	1	0	(1,1,8)	$\bar{Q}_L \gamma^\mu Q_L$
$IX_{s,o}$	1,8	3	0	(1,1,8)	$\bar{Q}_L \gamma^\mu Q_L$
$X_{\bar{3},6}$	$\bar{3}$,6	2	-1/6	(1,3,3)	$\bar{d}_R \gamma^\mu Q_L^c$
$XI_{\bar{3},6}$	$\bar{3}$,6	2	5/6	(3,1,3)	$\bar{u}_R \gamma^\mu Q_L^c$

arXiv:0911.2225 arnold,posleov,trott wise

1102.3374 arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

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
S_I	1	2	1/2	$(3,1,\bar{3})$	$\bar{u}_R\ Q_L$
S_{II}	8	2	1/2	$(3,1,\bar{3})$	$\bar{u}_R\ Q_L$
S_{III}	1	2	-1/2	$(1,3,\bar{3})$	$\bar{d}_R\ Q_L$
S_{IV}	8	2	-1/2	$(1,3,\bar{3})$	$\bar{d}_R\ Q_L$
S_V	3	1	-4/3	(3,1,1)	$u_R\ u_R$
S_{VI}	$\bar{6}$	1	-4/3	$(\bar{6},1,1)$	$u_R\ u_R$
S_{VII}	3	1	2/3	(1,3,1)	$d_R\ d_R$
S_{VIII}	$\bar{6}$	1	2/3	$(1,\bar{6},1)$	$d_R\ d_R$
S_{IX}	3	1	-1/3	$(\bar{3},\bar{3},1)$	$d_R\ u_R$
S_X	$\bar{6}$	1	-1/3	$(\bar{3},\bar{3},1)$	$d_R\ u_R$
S_{XI}	3	1	-1/3	$(1,1,\bar{6})$	$Q_L\ Q_L$
S_{XII}	$\bar{6}$	1	-1/3	(1,1,3)	$Q_L\ Q_L$
S_{XIII}	3	3	-1/3	(1,1,3)	$Q_L\ Q_L$
S_{XIV}	$\bar{6}$	3	-1/3	$(1,1,\bar{6})$	$Q_L\ Q_L$
$S_{H,8}$	1, 8	2	1/2	(1,1,1)	$\bar{Q}_L u_R,\ \bar{Q}_L d_R$

Lots of options as generically they have the right symmetry structure.

Just phenomenological models for $A_{FB}^{t\,\bar{t}}$? How does that solve the hierarchy?

We are all worms, but I do believe I am a glow-worm." -- **Winston Churchill**

Flavour Symmetric Models

Constraints on the tree level couplings to quark bilinear growing stronger....
But AFB required couplings can still be accommodated with flavour splitting.

S_V^3 Mass	TeV M_{jj}	LHC M_{jj}	TeV χ	LHC χ	S_{VI} Mass	TeV M_{jj}	LHC M_{jj}	TeV χ	LHC χ
300	1.0	-	1.2	1.1	300	0.3	-	0.4	0.5
500	1.2	n.b.	0.5	0.9	500	0.3	2.2	0.2	0.5
700	2.0	0.7	0.7	0.6	700	0.6	0.2	0.2	0.2
900	2.5	0.3	0.6	0.5	900	0.7	0.1	0.2	0.2
1100	2.8	0.4	0.5	0.6	1100	1.4	0.1	0.2	0.1
1300	4.0	0.5	1.3	0.6	1300	1.6	0.1	0.7	0.1
1500	6.0	0.6	1.6	0.3	1500	1.8	0.1	0.8	0.1
1700	n.b.	0.6	1.8	0.5	1700	2.0	0.1	0.8	0.1
1900	n.b.	0.6	2.0	0.4	1900	2.6	0.1	0.9	0.1
2100	n.b.	0.7	2.1	0.6	2100	3.0	0.1	1.0	0.1

t channel models M_{jj} constraints weaker due to sudakovs

TABLE V: Approximate upper bounds on the couplings of the scalars S_V, S_{VI} to light quarks due to the measured dijet invariant mass spectra (labeled M_{jj}) and angular distributions (labeled χ) at the tevatron and LHC, as explained in the text. The masses correspond to the scalar field flavors S_V^3 and $S_{VI}^{11=22=12}$. If no bound is determined we denote this with "n.b.".

arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

Flavour Symmetric Models

Some typical vector constraints from dijets.

	$\mathrm{II_o}$				$\mathrm{VI_o}$				$\mathrm{VI_s}$			
Mass	TeV M_{jj}	LHC M_{jj}	TeV χ	LHC χ	TeV M_{jj}	LHC M_{jj}	TeV χ	LHC χ	TeV M_{jj}	LHC M_{jj}	TeV χ	LHC χ
300	0.4	-	0.9	1.7	0.6	-	1.4	2.2	0.6	-	1.7	1.4
500	0.4	0.8	0.3	1.3	0.4	0.9	0.4	1.5	0.5	1.0	0.5	1.4
700	0.4	0.8	0.3	0.9	0.4	1.0	0.5	1.0	0.5	1.1	0.6	1.2
900	0.3	0.3	0.2	0.7	0.5	0.3	0.3	0.9	0.6	0.3	0.4	1.0
1100	0.4	0.3	0.4	0.8	1.1	0.4	0.6	1.0	1.3	0.5	0.8	1.2
1300	0.7	0.5	1.1	0.9	1.0	0.6	1.6	1.2	1.2	0.6	1.6	1.2
1500	2.7	0.5	2.6	0.9	4.8	0.6	4.3	1.1	3.4	0.7	3.1	1.2
1700	4.0	0.5	3.5	1.2	6.4	0.7	5.7	1.6	4.8	0.7	4.1	1.6
1900	5.3	0.7	4.4	1.0	7.7	0.9	6.5	1.3	6.1	0.8	4.8	1.4
2100	6.5	0.8	5.2	1.4	8.8	1.0	7.2	1.8	7.8	0.8	5.6	1.8

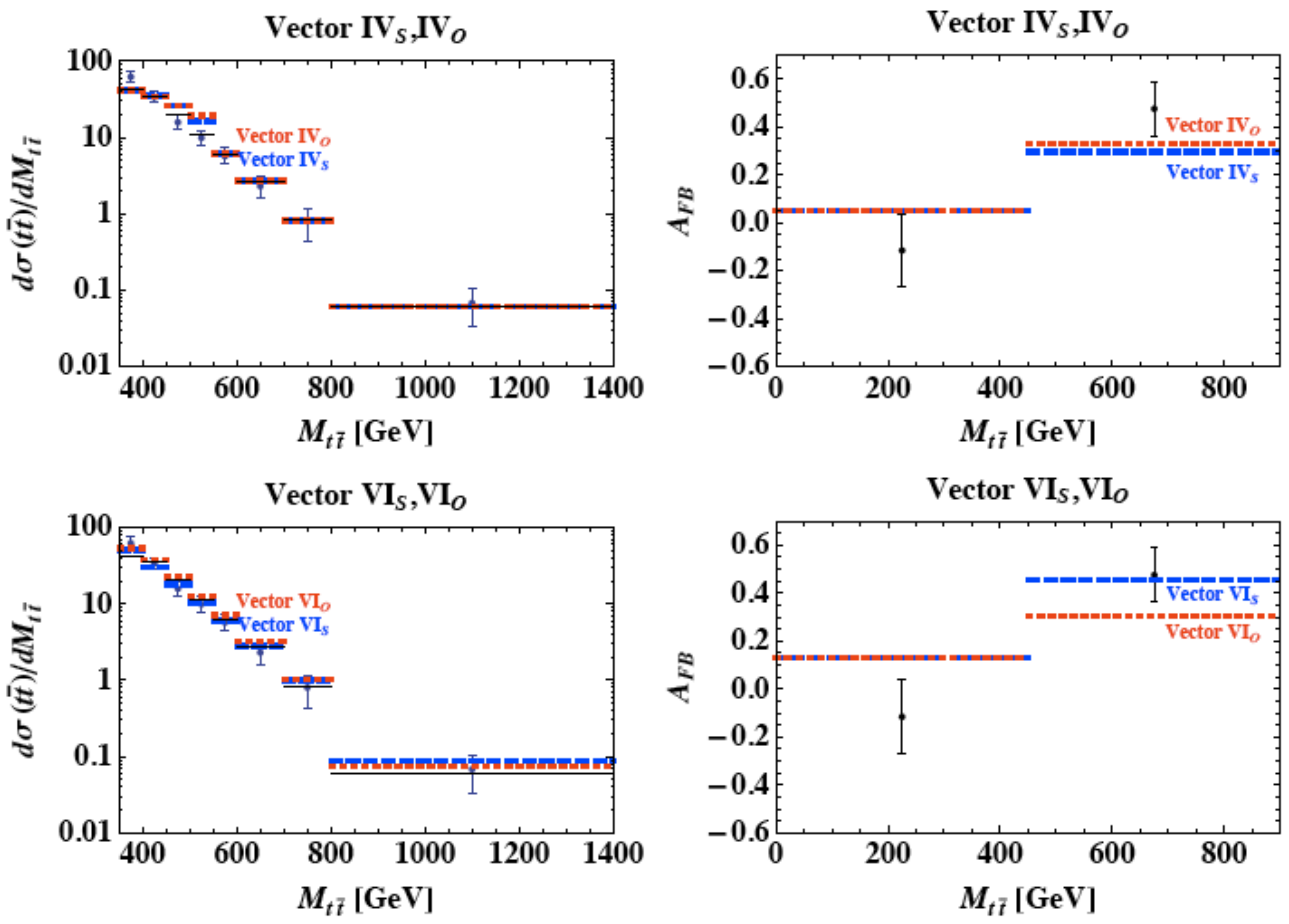
TABLE VI: Approximate upper bounds on the couplings f_q of the vectors $\mathrm{II_o}$, $\mathrm{VI_o}$ and VI_s to light quarks, due to the measured dijet invariant mass spectra (labeled M_{jj}) and angular distributions (labeled χ) at the Tevatron and LHC, as explained in the text.

t channel models

Mjj constraints weaker due to sudakovs

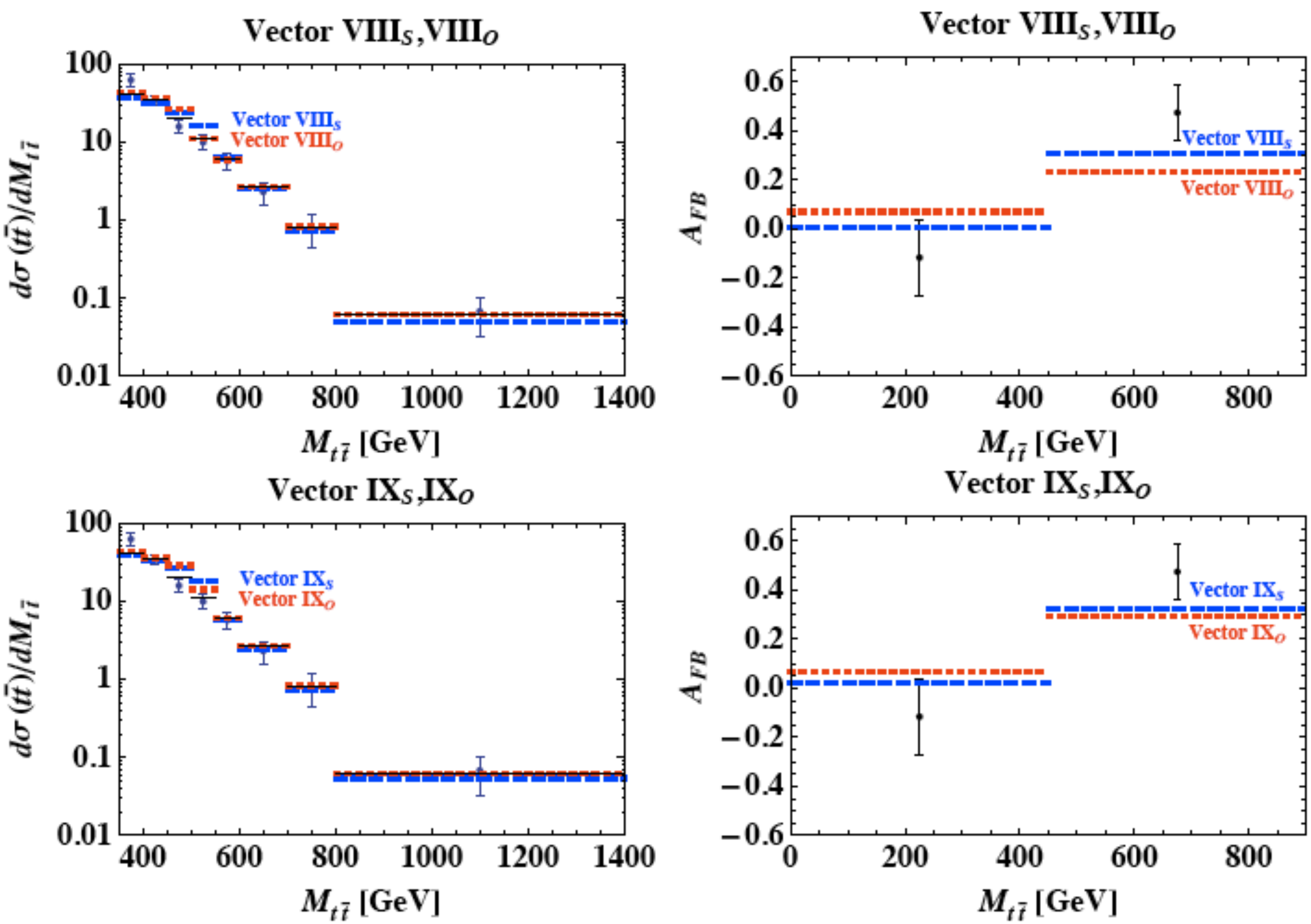
arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

Flavour Symmetric Models



arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

Flavour Symmetric Models

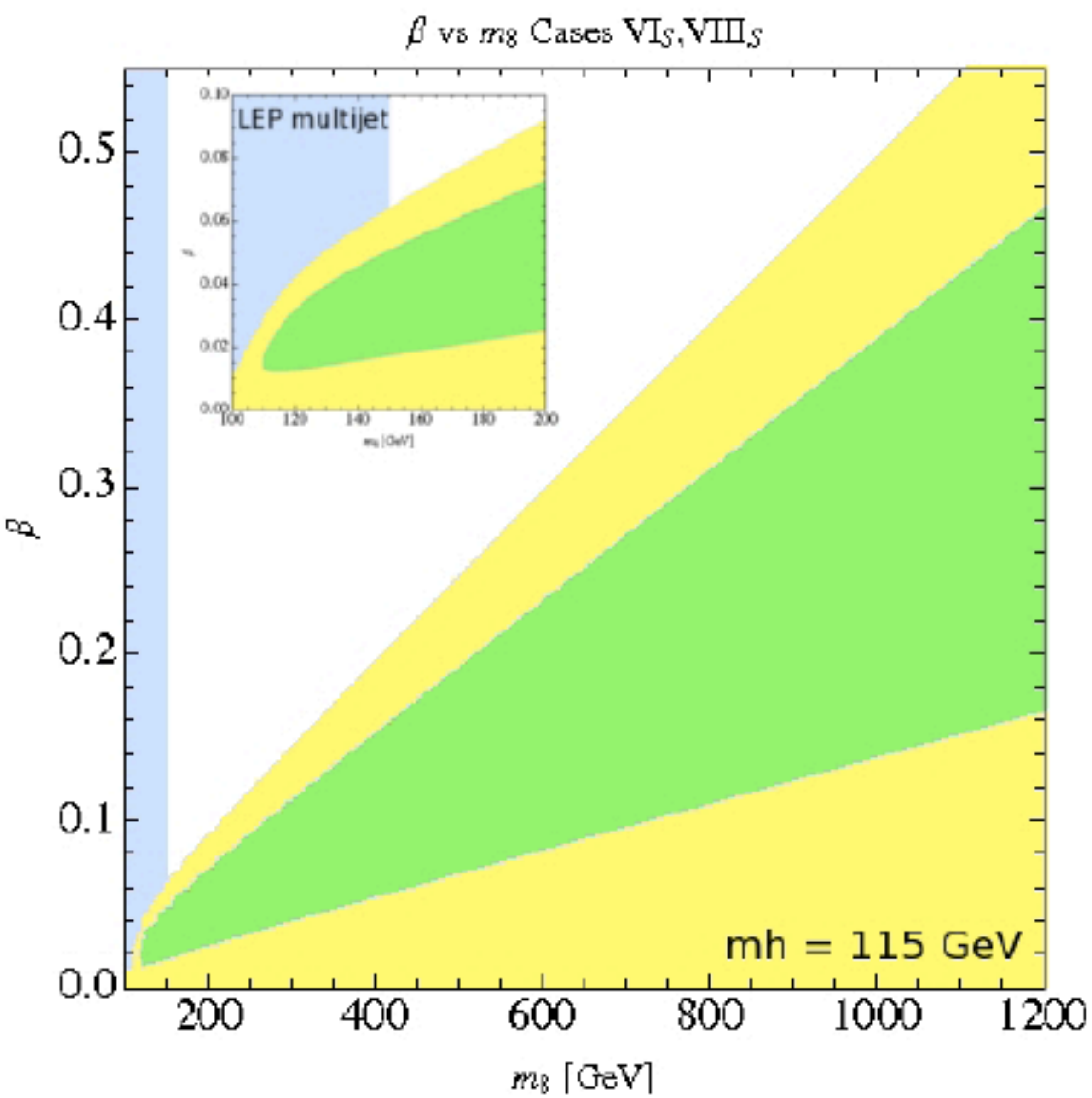


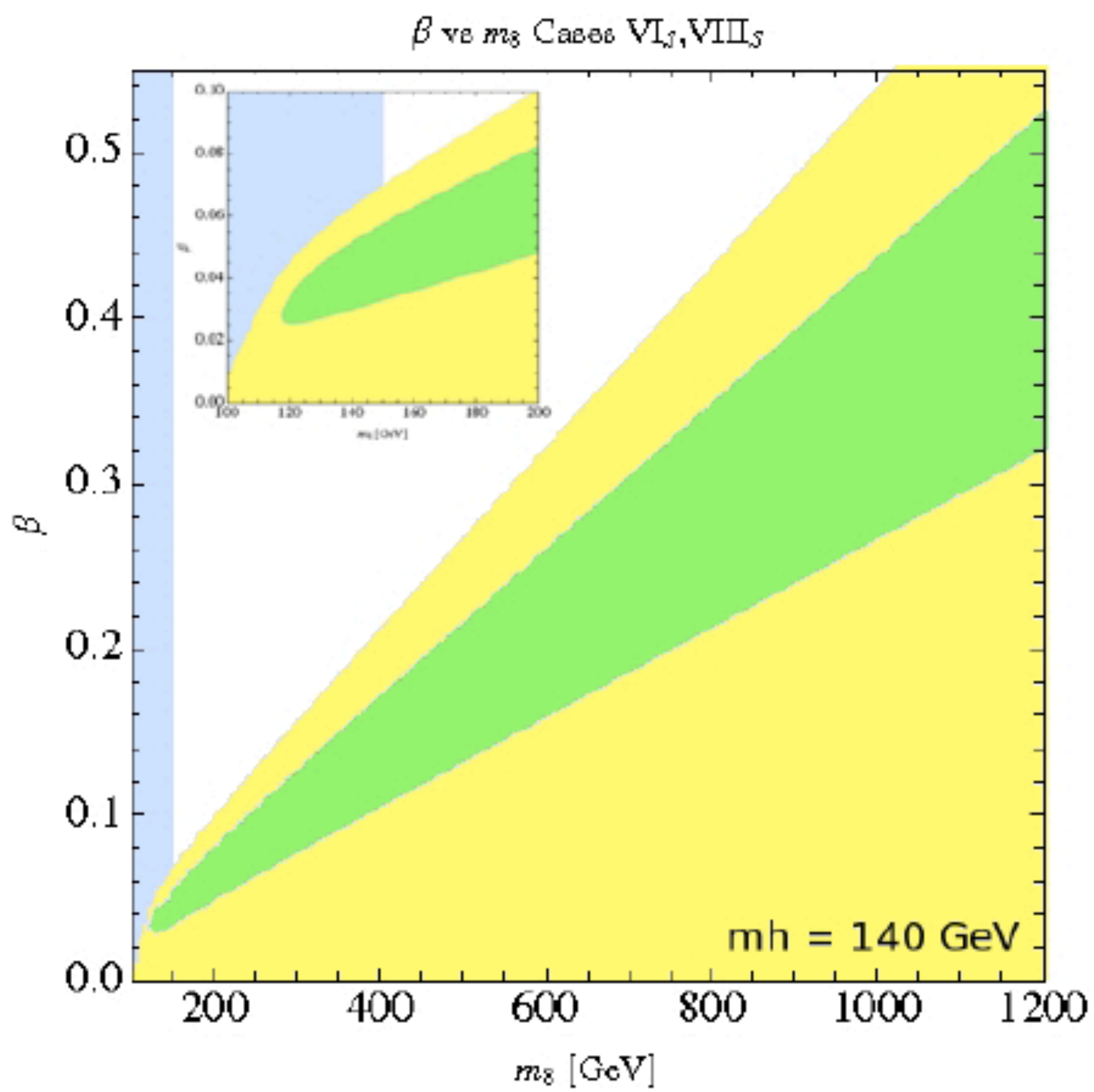
arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

FIG. 9: Predictions for $d\sigma/dM_{t\bar{t}}$ and A_{FB} for a set of vector models, $\mathrm{IV_{s,o}}, \mathrm{VI_{s,o}}, \mathrm{VIII_{s,o}}, IX_{s,o}$ fixing m_V =500 GeV (except for $\mathrm{VI_{s,o}}$ where m_V =350 GeV, and using flavor breaking choices for couplings to quarks; $(\sqrt{f_q f_t}, f_{qt})$ = $(0.1, 0.3)\mathrm{IV_s}$; $(0.1, 0.3)\mathrm{IV_o}$; $(0.55, 1.3)\mathrm{VI_s}$; $(0.55, 1.3)\mathrm{VI_o}$ and (η_1, η_2) = $(1.4, -0.4)\mathrm{VIII_s}$;

Flavour Symmetric Models

We recently checked EWPD for the vectors. Flavour 8's can impact Higgs searches dramatically. $\mathscr{L}_C^{\rm int} = -\beta \, {\rm Tr}\left(V_\mu^s \, \Delta_C\right) H^\dagger D^\mu H,$





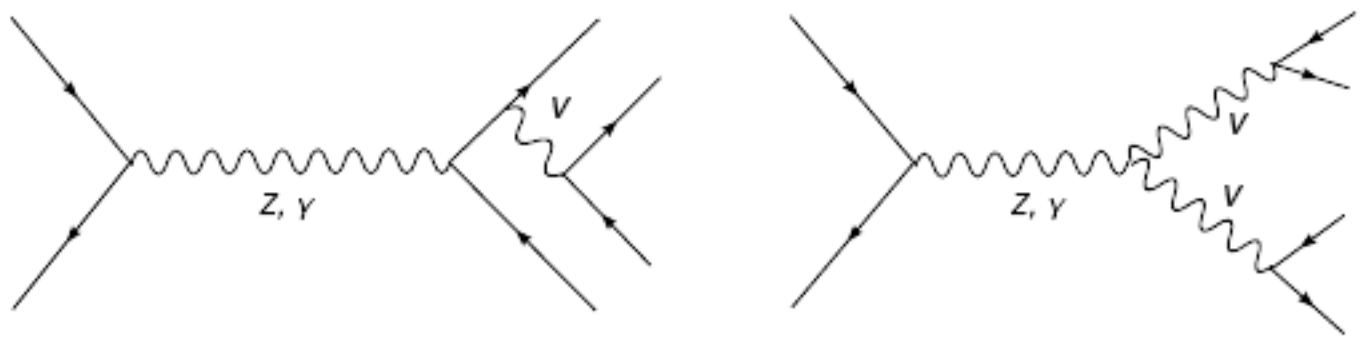
arXiv: 1110.5361 Grinstein,Murphy Trott

Heavier Higgs more consistent with the data... *obligatory higgs effects*

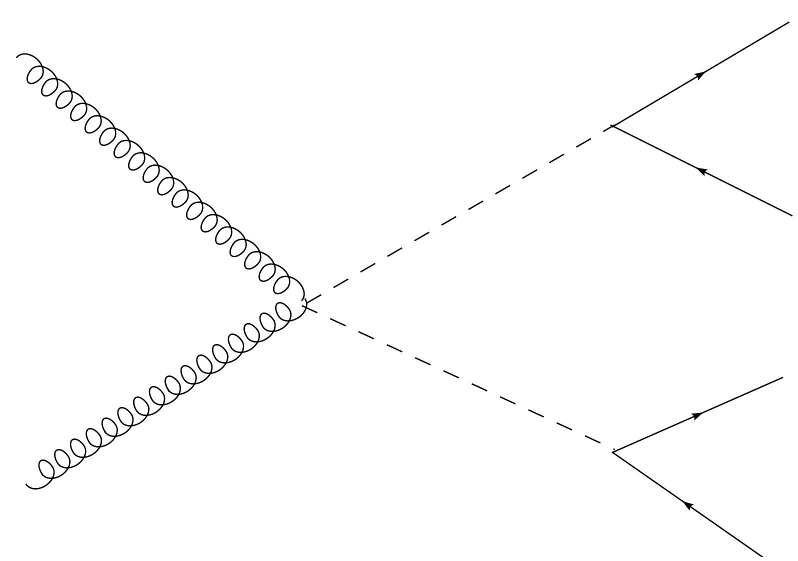
Collider constraints closing in

Problem with the dijet constraints is unknown normalization parameters.

Constraints based on gauge couplings lead to direct mass bounds.



Past LEP bounds when colour or flavour symmetry does not protect ~ 150 GeV



This search at LHC has got to be done, we should look for coloured fields with kinetic terms. We didn't at the tevatron.

Collider constraints closing in

Problem with the dijet constraints is unknown normalization parameters.

Constraints based on gauge couplings lead to direct mass bounds.

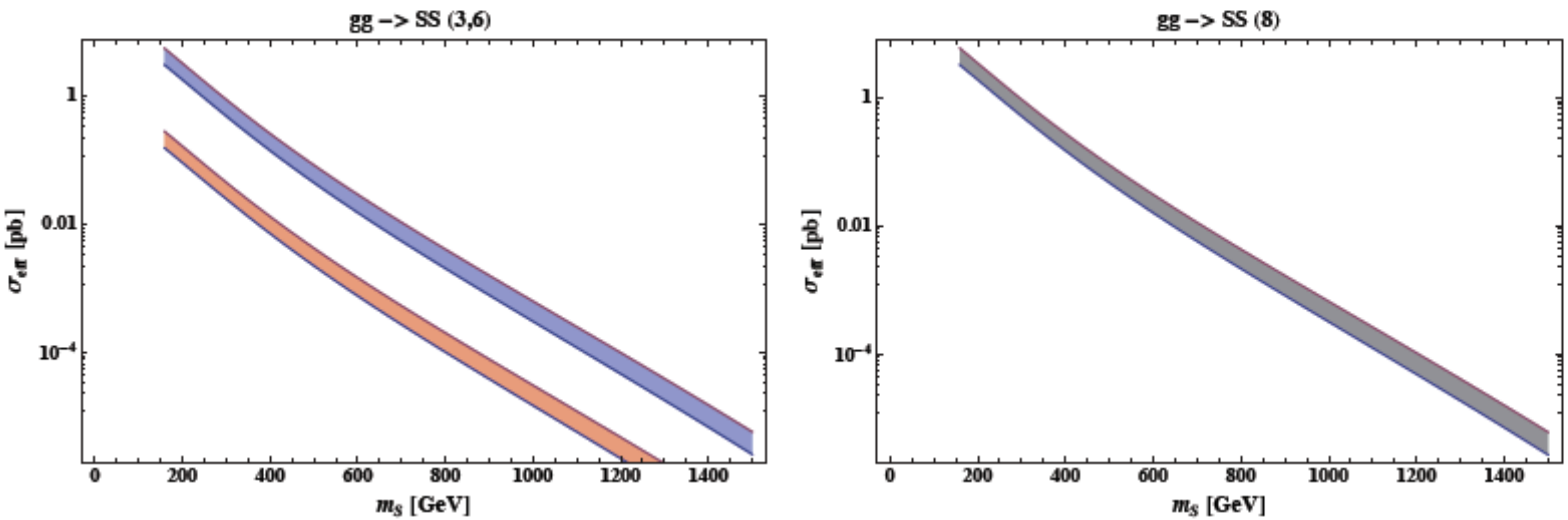


FIG. 13: Production cross sections of $g\,g \to S\,S$ for color triplets (red left), sextets (blue left) and octet (grey right) scalar field S. We show $\sigma_{eff} = \sigma/\mathrm{dim}[F]$ for a single flavor. We use MSTW208 pdfs and the PDF error bands shown are defined by taking $\mu = [2(2m_S), (2m_S)/2]$. Details of the calculation are in the Appendix.

arXiv: 1108.4027 Grinstein,Kagan Trott Zupan,

Collider constraints closing in

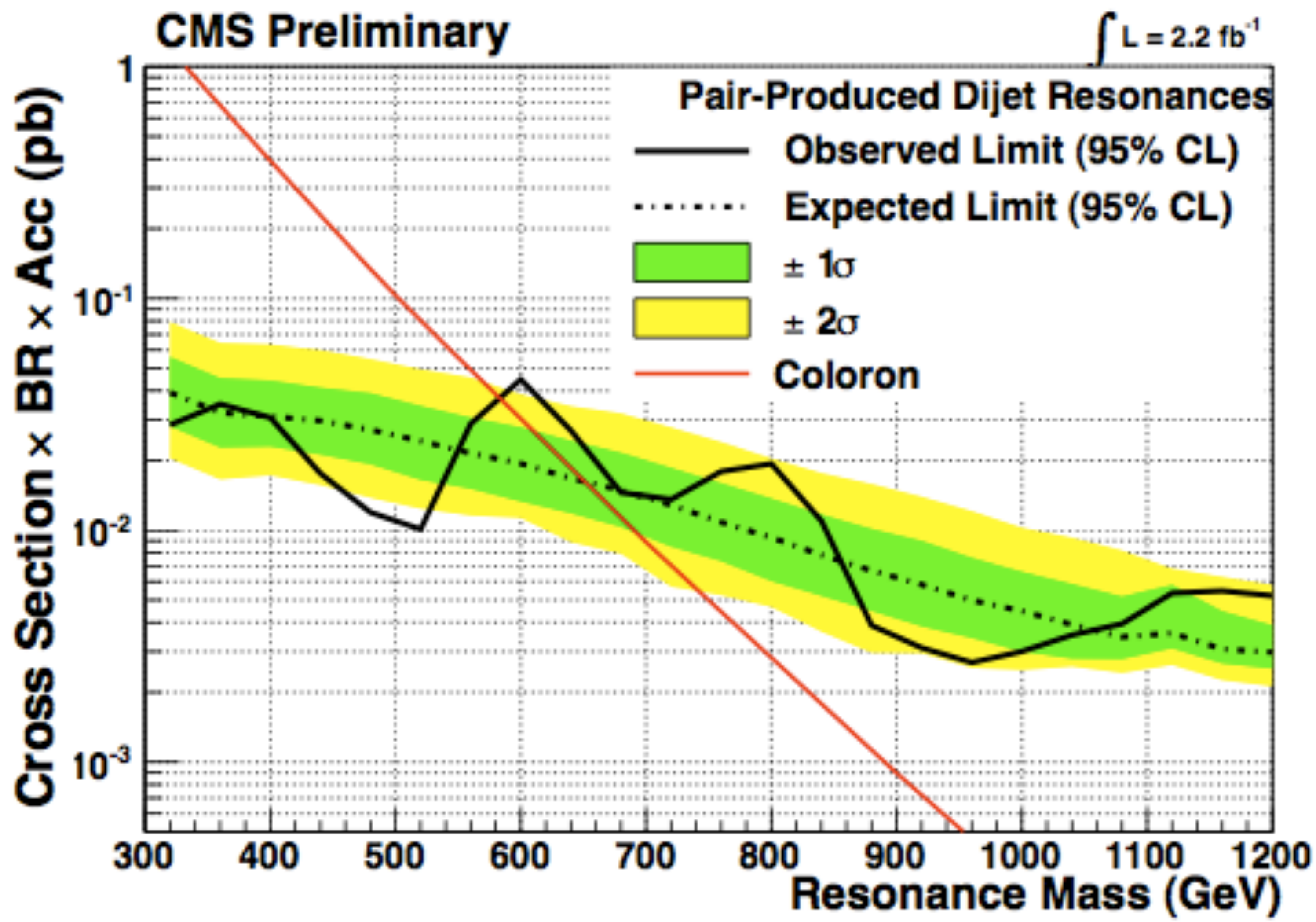


Figure 6: The observed limit on the cross section times branching fraction times acceptance for pair production of dijet resonances (solid black curve), and the expected limit (dot dashed curve) and its 1σ and 2σ variations (shaded), are compared with the theoretical predictions for the coloron model (red curve). We exclude at 95% C.L. pair production of colorons with mass $M(C)$ in the range $320 < M(C) < 580\,\mathrm{GeV}/c^2$.

Watch these studies - things are on the edge of discovery/being ruled out that are coloured associated with $A_{FB}^{t\,\bar{t}}$ that are flavour symmetric.

Conclusions

The current experimental status of $A_{FB}^{t\,\bar{t}}$ remains very interesting.

Updates today at Moriond will reset the discussion on models.

People have been trying to explain deviations that were TOO BIG.
This became clear when you studied related spectra.

The SM calc has been refined upwards. EW Sudakovs lead to a slight enhancement. EW Sudakovs open the widow for NP a bit wider.

The flavour symmetric effective fields have a shot! A good one.

The new data will lead to N more papers, where N is a large number.