A_{FB} *met* LHC

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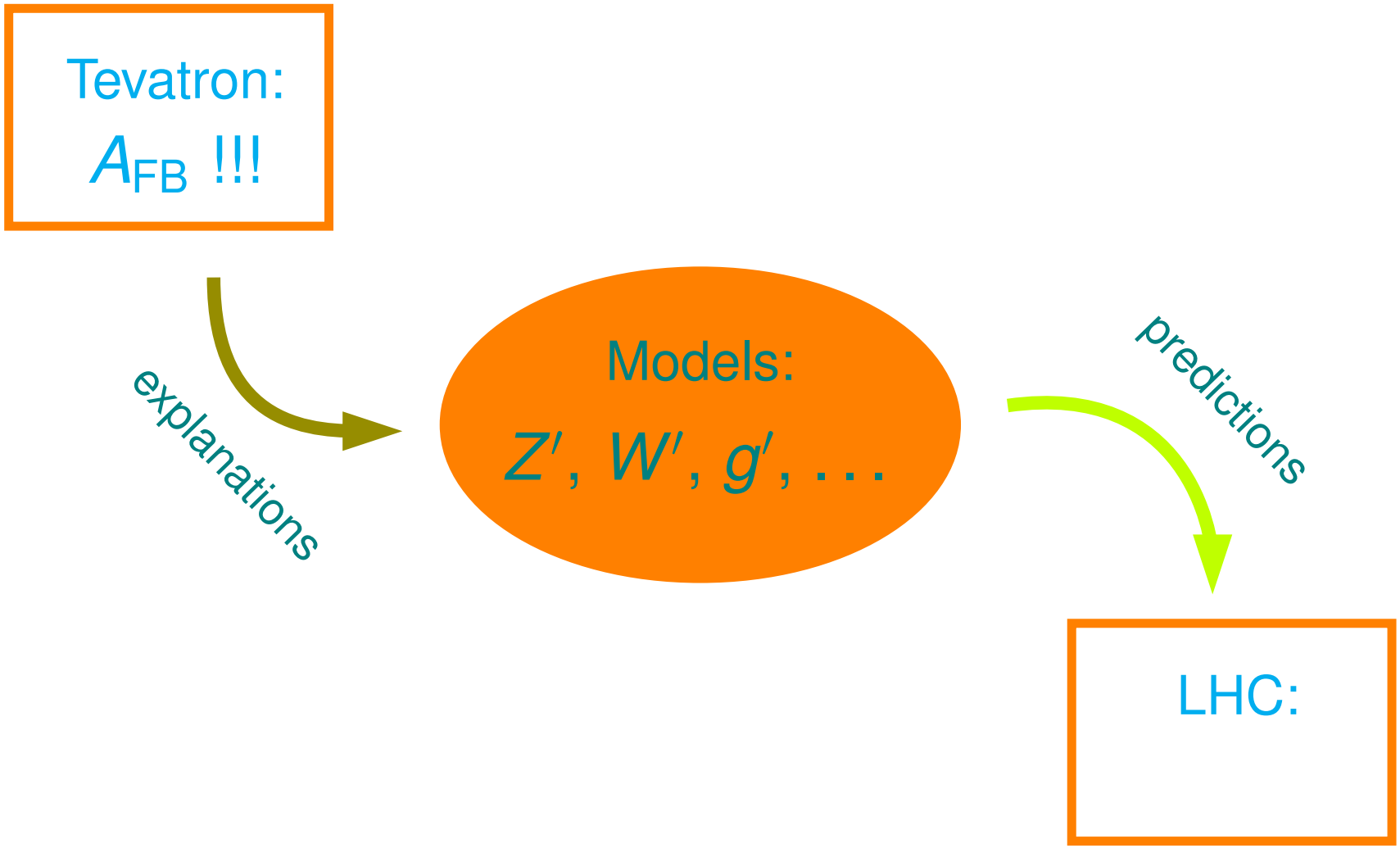
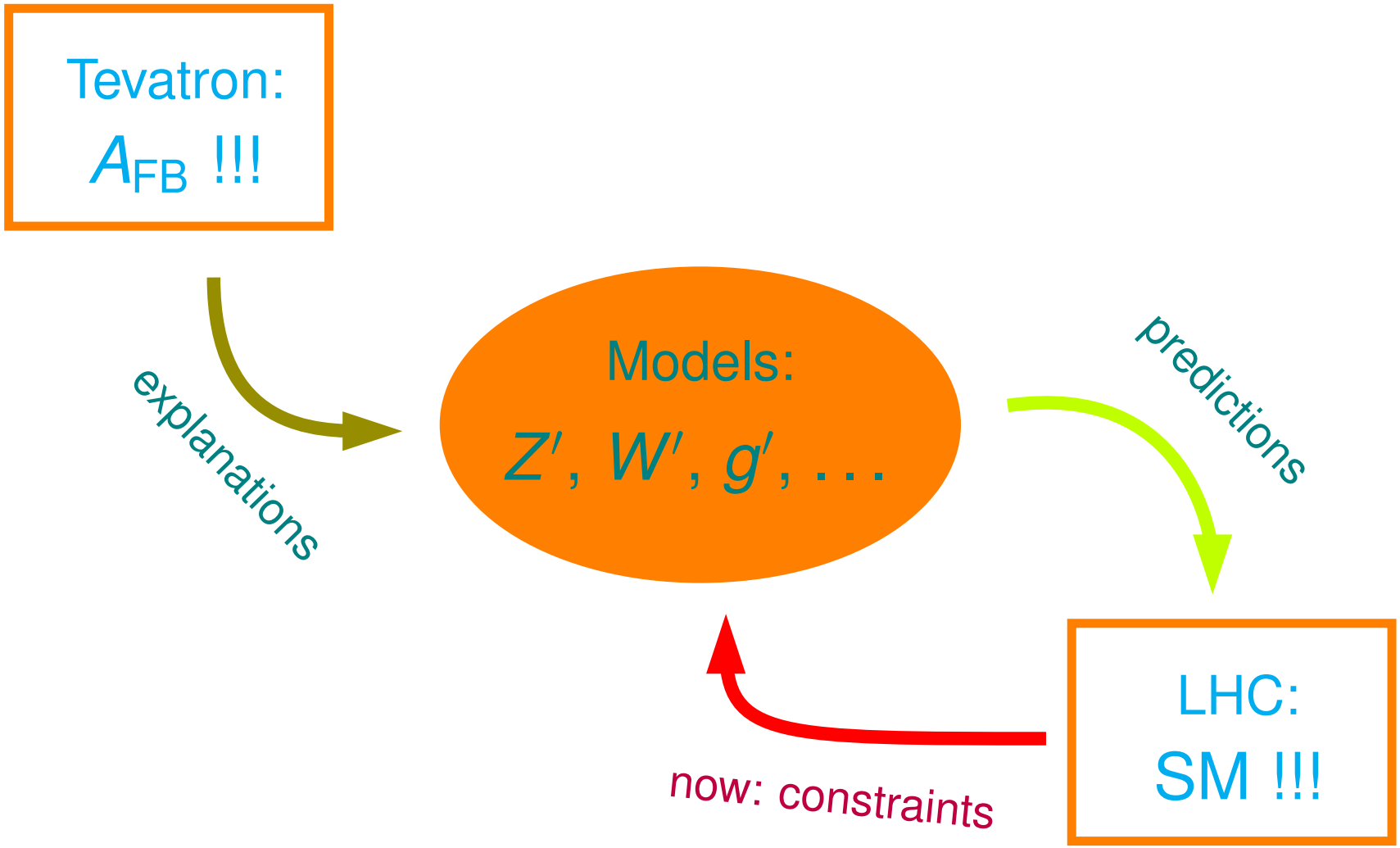
Workshop “Implications of LHC results for TeV scale physics”,
CERN, August 31st 2011

Status of A_{FB}: experiments vs theories



Status of A_{FB}: experiments vs theories



Timeline of Tevatron measurements

1995 – 2010

up to $\sim 2\sigma$ asymmetry excess in D0 & CDF measurements

01/2011

high-mass measurement by CDF triggers paper flood

$$A_{\rm FB} = 0.158 \pm 0.075 \text{ (inclusive)} \qquad \text{SM: } 0.058 \quad 1.3\sigma$$

$$A_{\rm FB} = 0.475 \pm 0.114 \ (m_{t\bar{t}} > 450 \text{ GeV}) \qquad \text{SM: } 0.088 \quad 3.4\sigma$$

07/2011

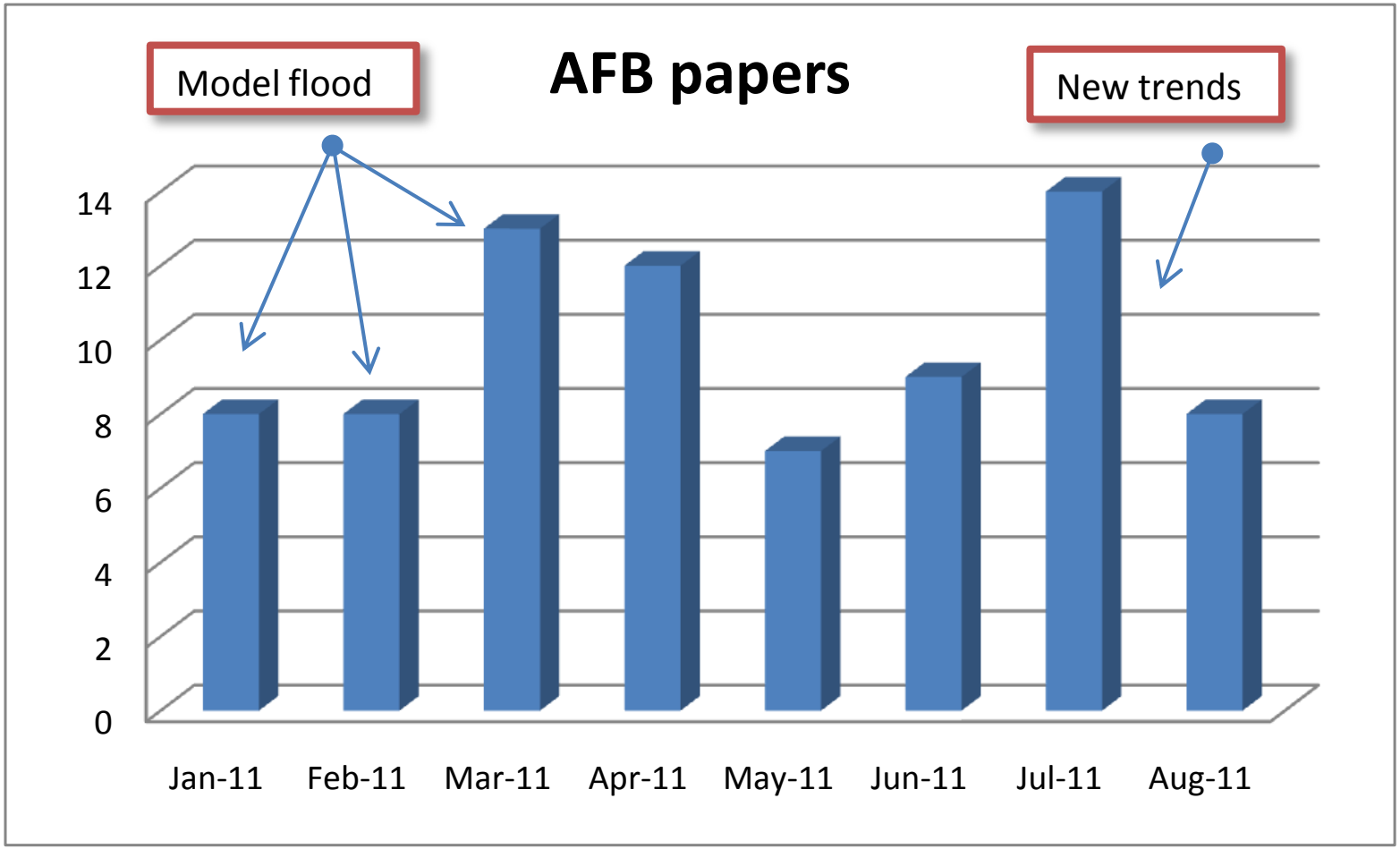
long awaited D0 measurement confirms inclusive but not high-mass $A_{\rm FB}$

updated SM predictions reduce discrepancies 1107.2606

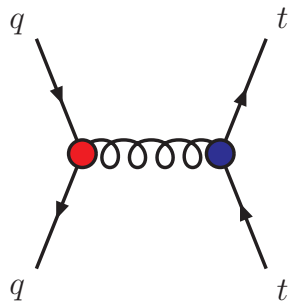
$$A_{\rm FB} = 0.196 \pm 0.065 \text{ (inclusive)} \qquad \text{SM: } 0.0893 \quad 1.6\sigma$$

$$A_{\rm FB} \sim 0.2 \ (m_{t\bar{t}} > 450 \text{ GeV}) \qquad \text{SM: } 0.139$$

Timeline of models



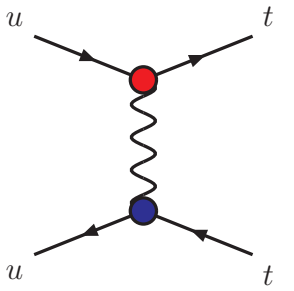
Most popular models



s channel:

$\mathcal{G}_\mu \sim (8,1)_0$ 0809.3354 , 0906.0604 , 0911.2955 , 1007.0243 , 1011.6380 , 1011.6557 , 1101.2902 , 1101.5203 , 1103.0956 1104.1917 , 1105.3158 , 1105.3333 , 1106.0529 , 1106.4054 , 1107.0978 , 1107.1473 , 1107.2120 , 1107.5769

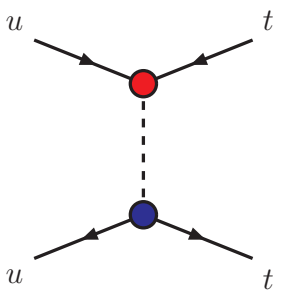
t channel:



$Z' \sim (1,1)_0$ 0907.4112 , 1101.4456 , 1101.5625 , 1102.0545 , 1103.1266 1103.4835 , 1104.1385 , 1104.3139 , 1106.5982 , 1108.0350 , 1108.1802

$W' \sim (1,1)_1$ 0908.2589 , 1002.1048 , 1003.3461 , 1101.1445 , 1101.5392 , 1102.0279 1104.0083 , 1105.4606

$\phi \sim (1,2)_{-\frac{1}{2}}$ 1104.4782 , 1107.0841 , 1107.4350 , 1108.4005



u channel:

$\omega^4 \sim (3,1)_{-\frac{4}{3}}$

$\Omega^4 \sim (\bar{6},1)_{-\frac{4}{3}}$

0911.3237 , 0911.4875 , 0912.0972 , 1007.2604 , 1102.3374 , 1102.4736 , 1103.2757 , 1108.4027

LHC: what to look for?

Various smoking guns related to A_{FB}:

- observation of new particles
- like-sign tops
- ...

whose non-observation (as yet) is unconclusive for models' fate

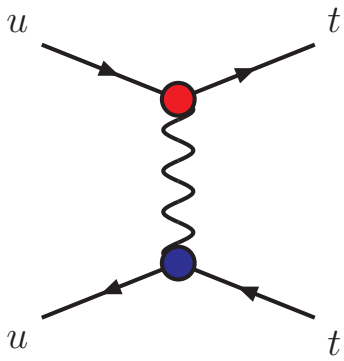
But other probes which are robust and hard-to-evade:

- charge asymmetry A_C measured ✔
- excess in $t\bar{t}$ invariant mass tail waiting ... ✘

☞ should be on top of CMS / ATLAS top physics wishlist !!!

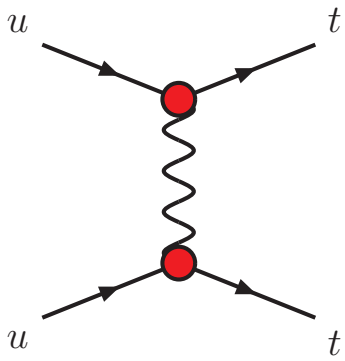
Smoking gun: like-sign tops (Z')

0907.4112, 1101.4456, 1101.5625, 1102.0545, 1104.1385



Z' real

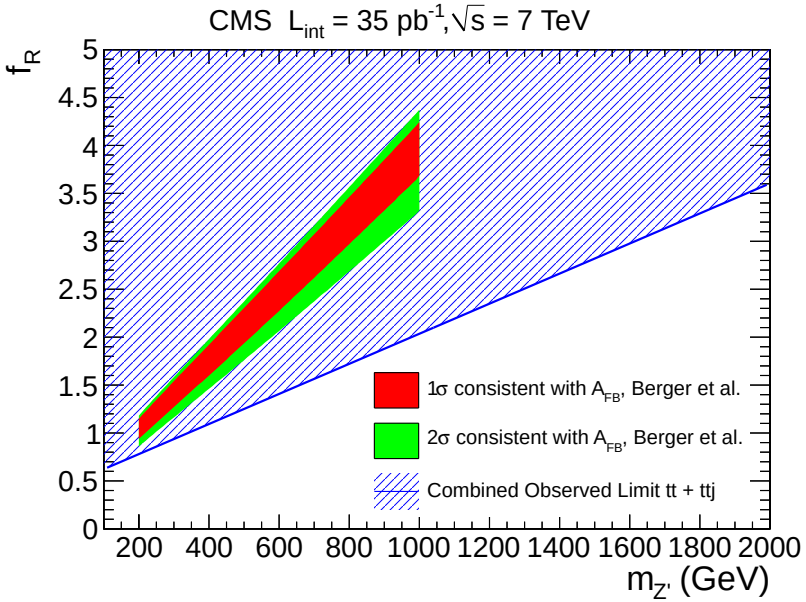
$\leftrightarrow$



But for complex Z': forget all this 1103.4835

No smoke, no gun: no like-sign tops

CMS plot

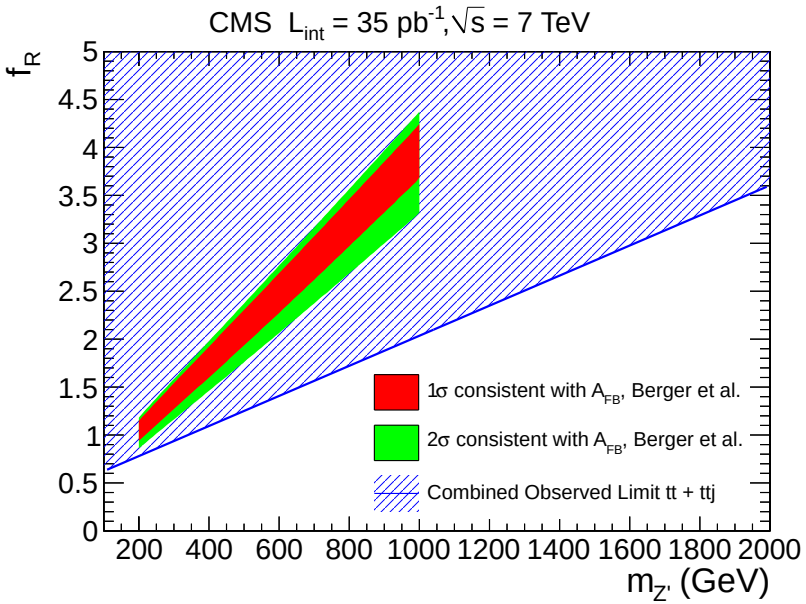


Excludes model parameter region consistent with $\sigma = 7.50 \pm 0.48$ pb, high-mass $A_{\mathrm{FB}} = 0.475 \pm 0.114$

What if A_{FB} not so large? (D0)

No smoke, no gun: no like-sign tops

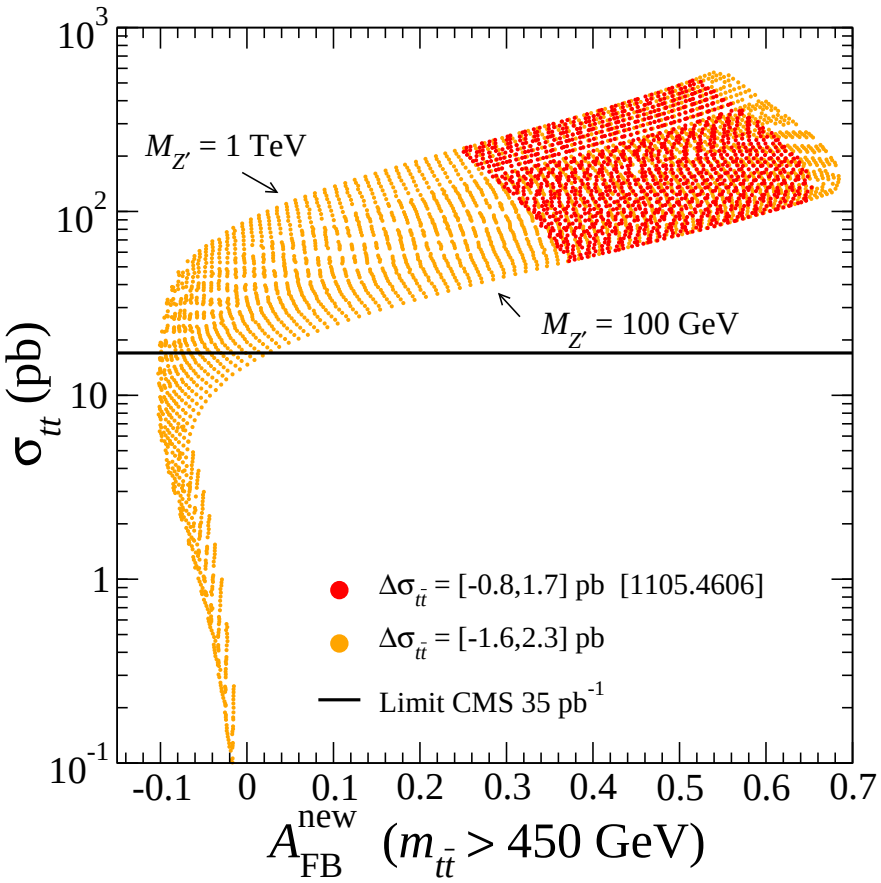
CMS plot



Excludes model parameter region consistent with $\sigma = 7.50 \pm 0.48$ pb, high-mass $A_{\rm FB} = 0.475 \pm 0.114$

What if $A_{\rm FB}$ not so large? (D0)

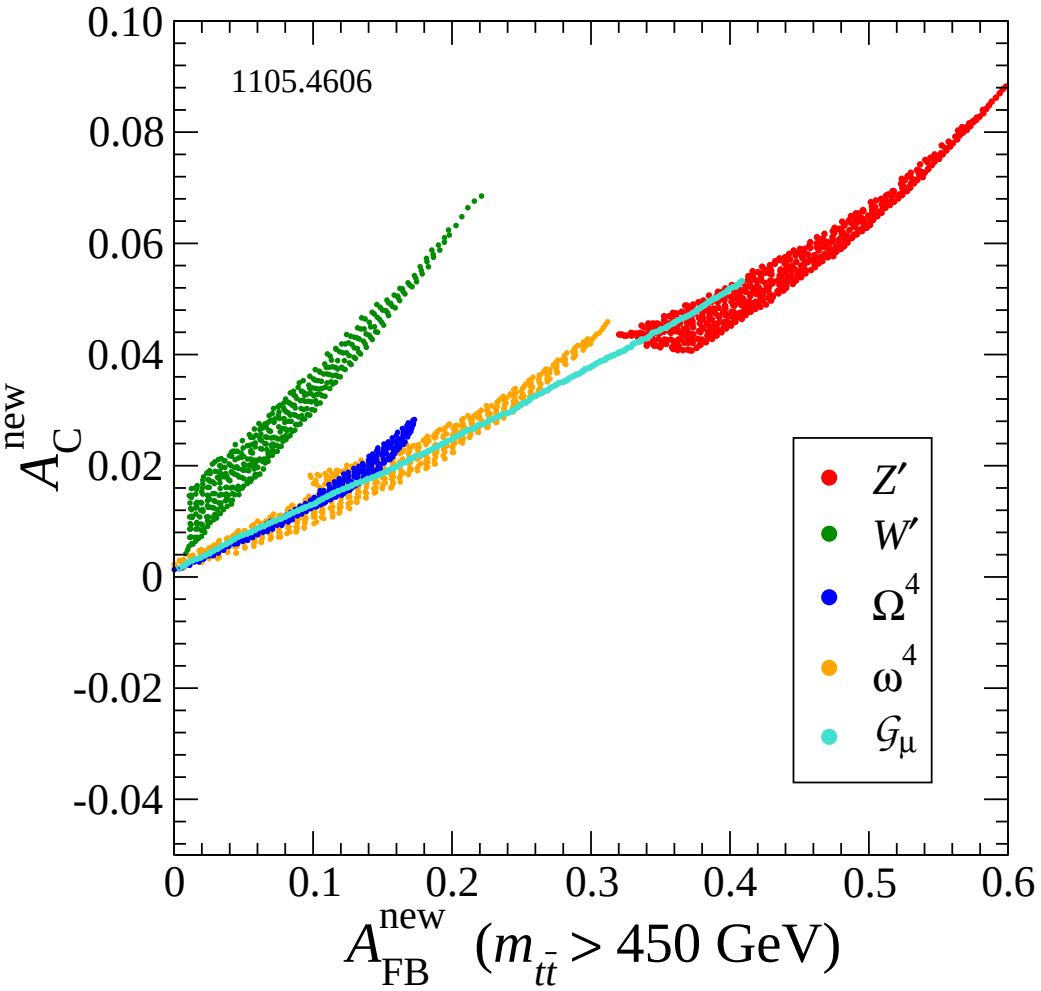
General exclusion plot



Z' coupling from 0 to $\Delta\sigma = 2.3$ pb

$A_{\rm FB}^{\rm new} > 0$ still allowed for light Z'

Predictions for LHC charge asymmetries



How to read the plot

Coloured regions:

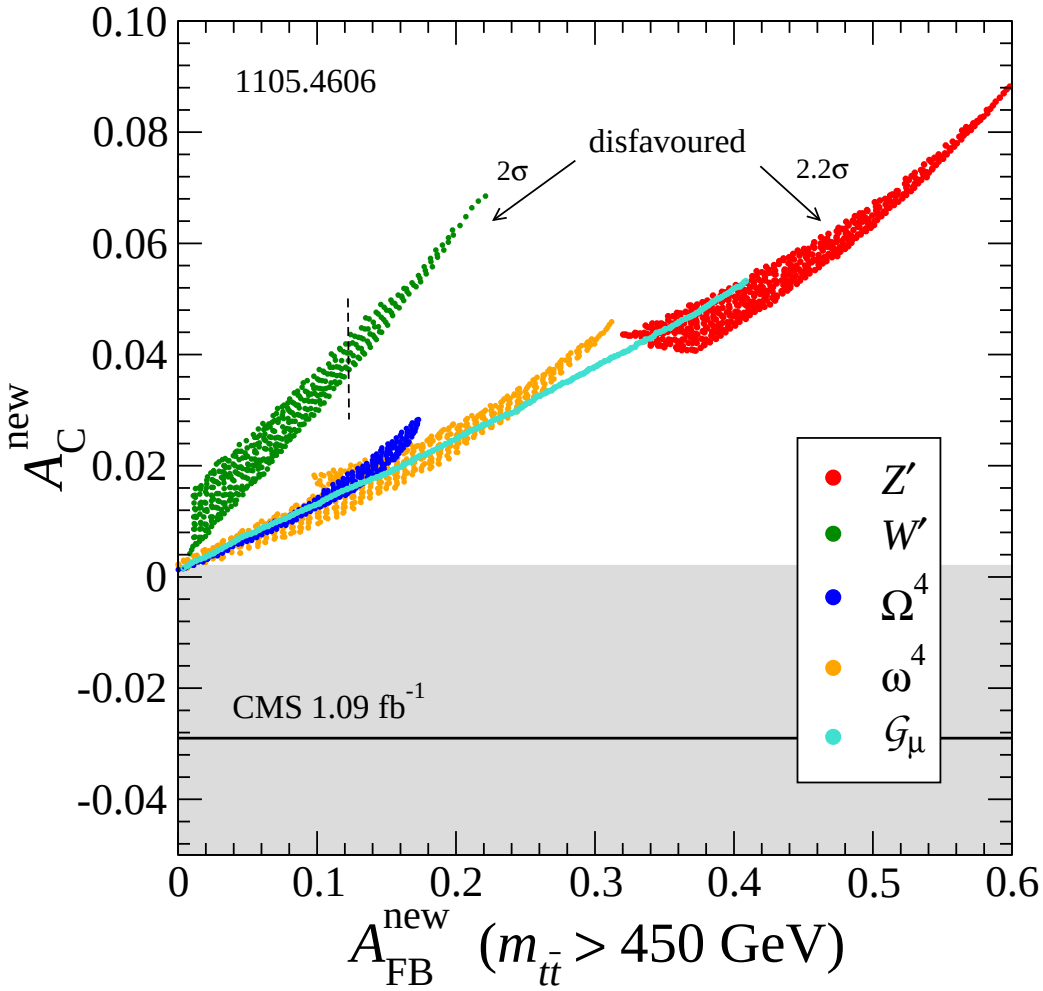
Tevatron $t\bar{t}$ xsec within 1σ

LHC $t\bar{t}$ tail not too large

X: Tevatron high-mass A_{FB}

Y: LHC inclusive A_C
(only NP contributions)

Constraints from LHC charge asymmetries



How to read the plot

Z': disfavoured

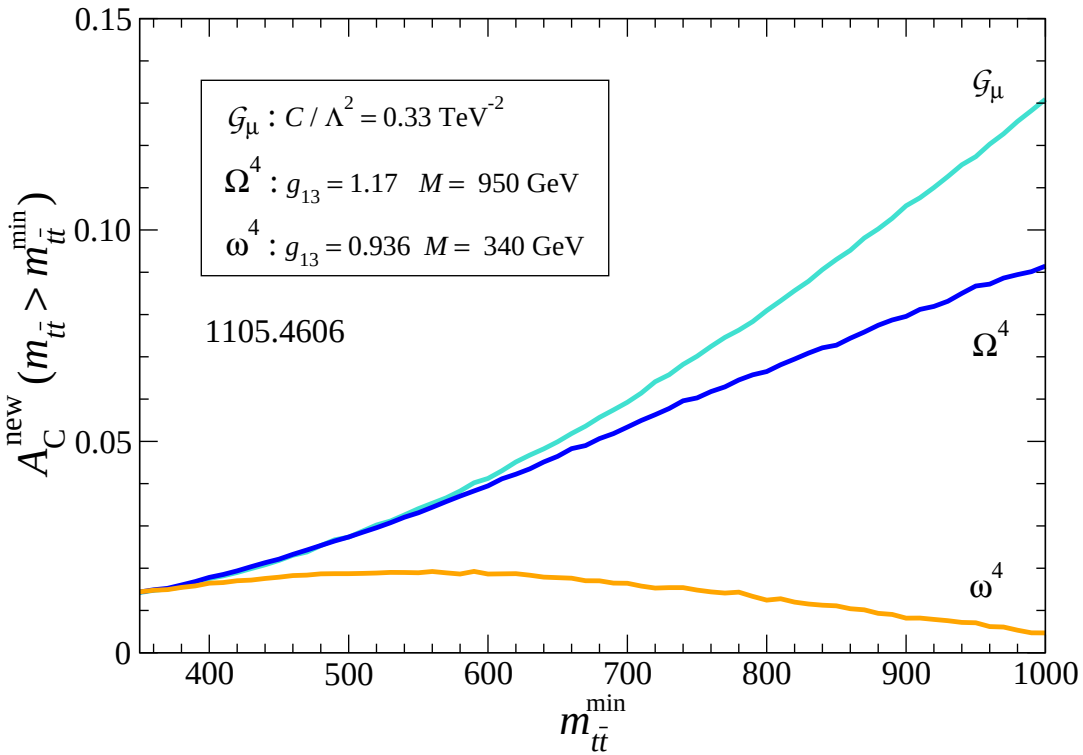
W': disfavoured if $A_{FB}^{new} \gtrsim 0.1$

also in D0 measurement

rest: some tension with CDF high-mass A_{FB}

Next in CMS / ATLAS “to do” list

Measure mass dependence of A_C



How to read the plot

Three benchmark points:
same high-mass A_{FB}
and inclusive A_C

X: cut on minimum $m_{t\bar{t}}$

Y: A_C
(only NP contributions)

CMS: apparently no A_C enhancement with $m_{t\bar{t}}$ → bad for heavy $\mathcal{G}_\mu$!!!

$t\bar{t}$ invariant mass tail

Measurement not yet addressed by CMS / ATLAS

despite its importance was pointed out months ago [1103.2297,1103.2765]

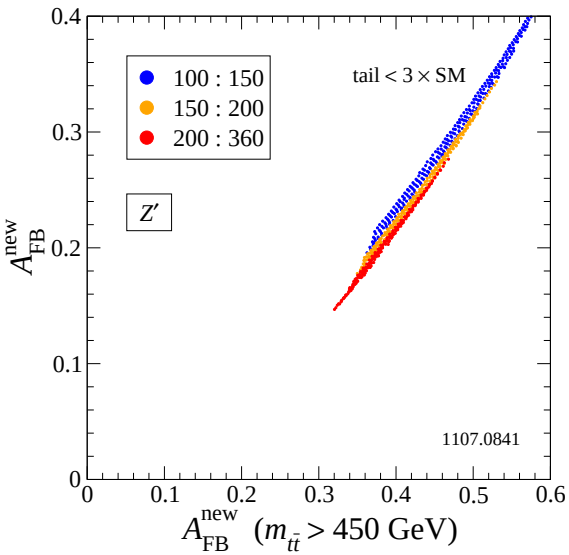
But public $m_{t\bar{t}}$ distributions scrutinised by theorists' sharp eye 🙂

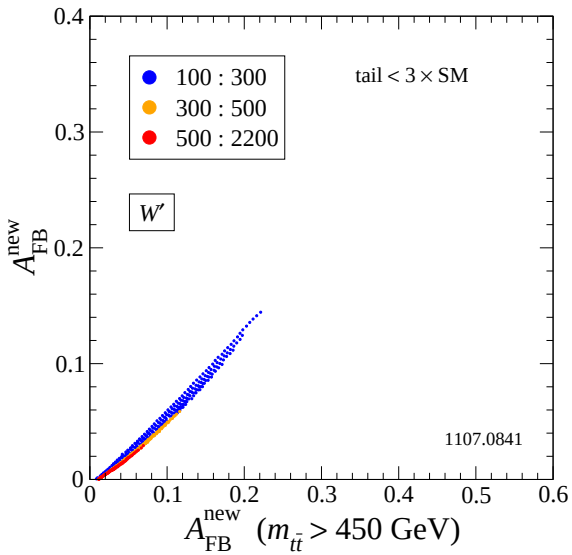
Result: $\sim$ agree with the SM CMS-PAS-EXO-11-055

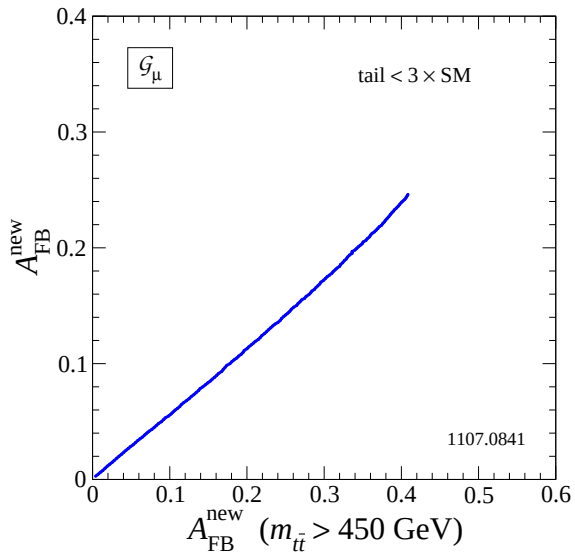
In the absence of a proper limit ➔ make estimations

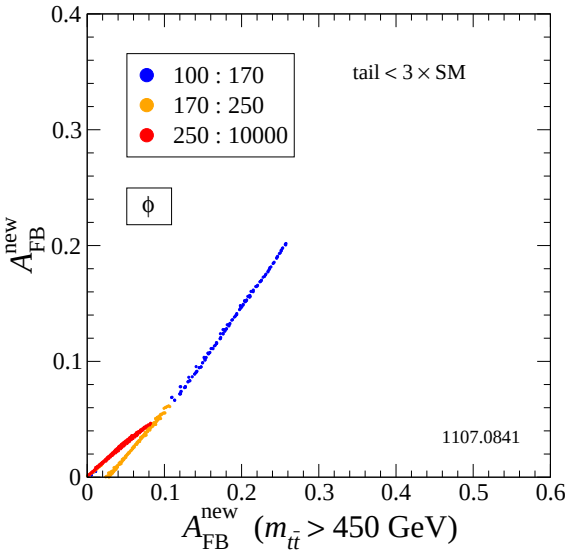
Constraints from $m_{t\bar{t}}$ tail

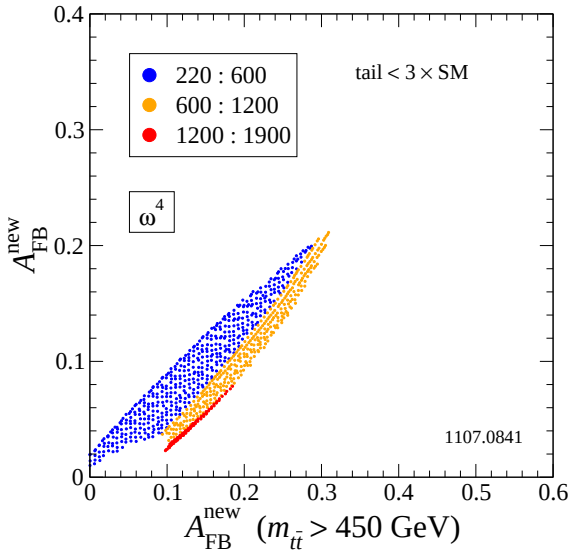
$\sigma(m_{t\bar{t}} > 1\ \text{TeV}) < 3 \times \text{SM}$

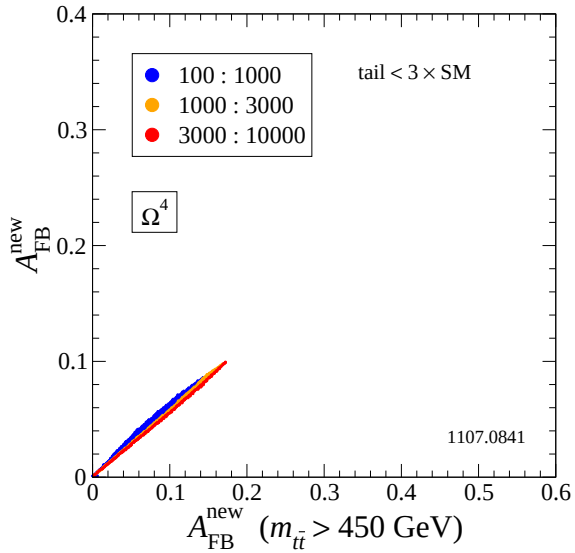




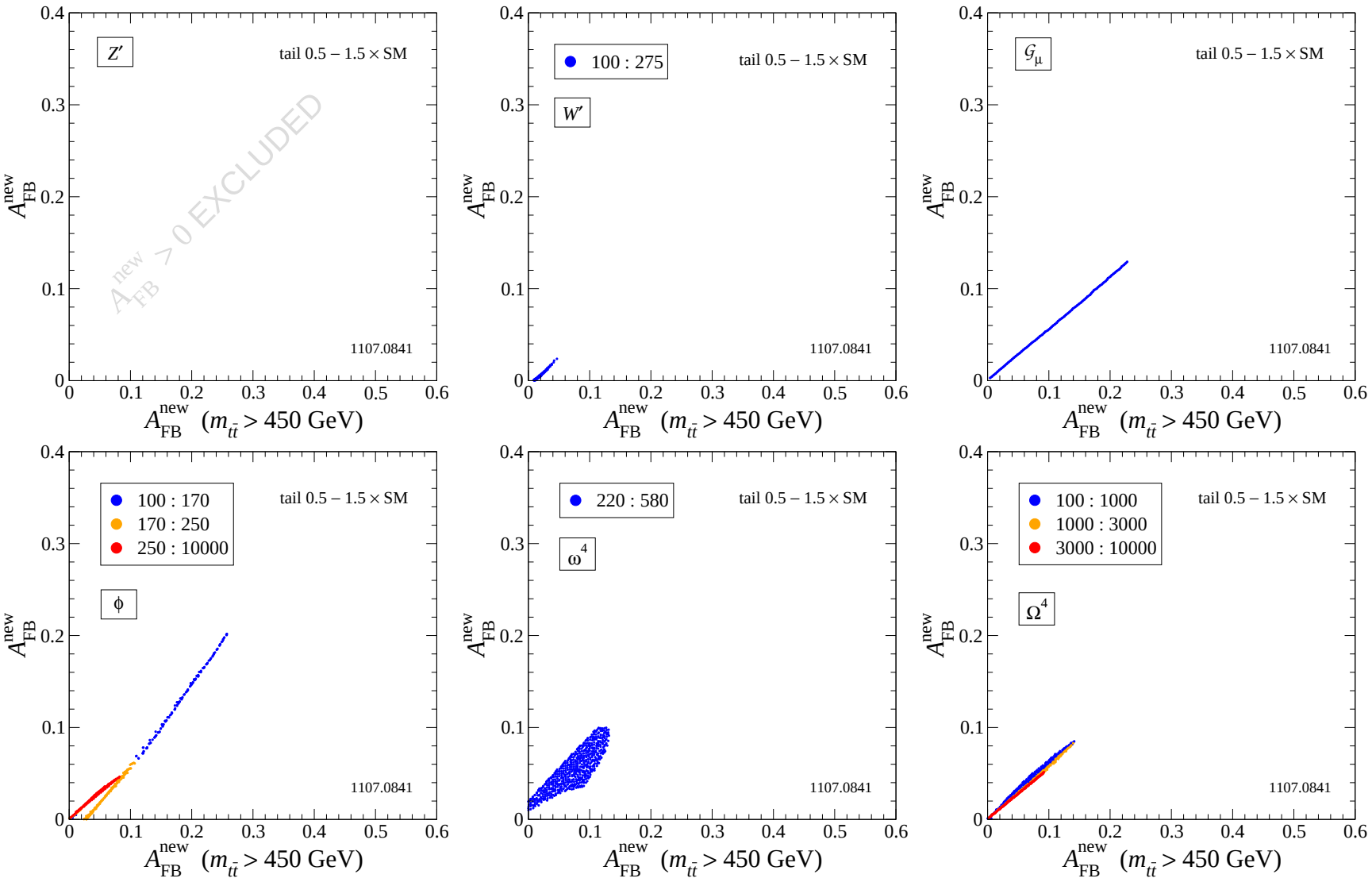








Constraints from $m_{t\bar{t}}$ tail $\quad \sigma(m_{t\bar{t}} > 1\ \text{TeV}) \in 0.5 - 1.5 \times \text{SM}$



Consequences of $t\bar{t}$ tail ~~measurement~~ theorists' guess

1. Z' models disfavoured
2. W' models disfavoured
3. heavy s-channel $\mathcal{G}_\mu$ must be very heavy and couple strongly
   ☞ ugly model
4. scalar ϕ: no problem ✔
5. exotic scalars: no problem if high-mass A_{FB} moderate

BUT

remember physics is an experimental science: models must be ruled out by experimentalists

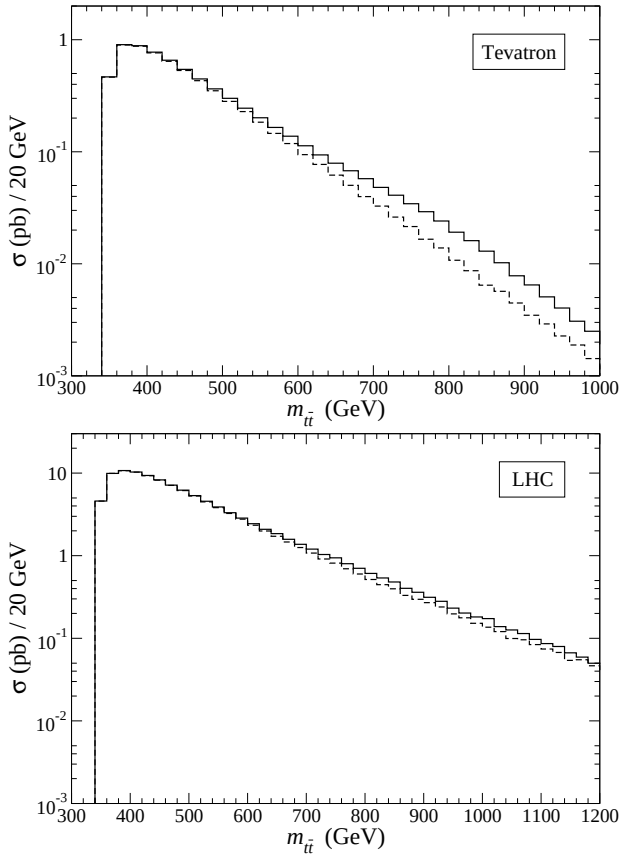
New trends

Models without a large $t\bar{t}$ tail

Example: “light” gluons with masses $M \lesssim 1$ TeV

1106.4054, 1107.0978, 1107.1473, 1107.2120

- invisible at Tevatron if very wide
- even more at LHC (gg fusion)
- small tail: gluon is lighter !!!
- diverse A_{FB} profiles vs $m_{t\bar{t}}$ possible

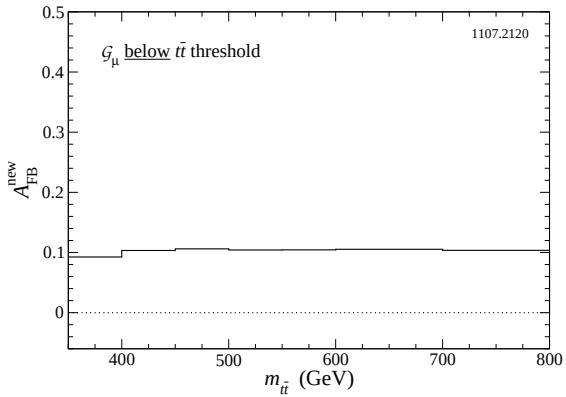


☞ talks by M. Schmaltz and M. Masip

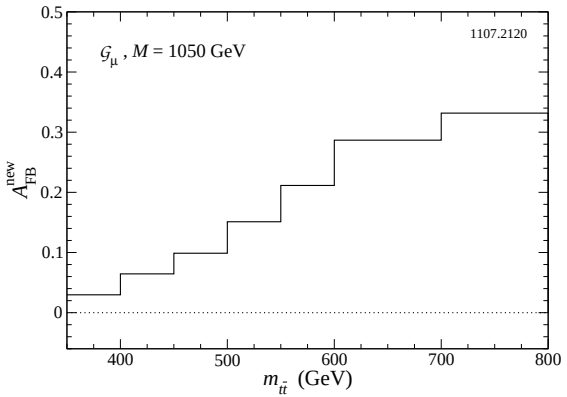
A_{FB} profiles: from D0's flat to CDF's camel

Sustainable model

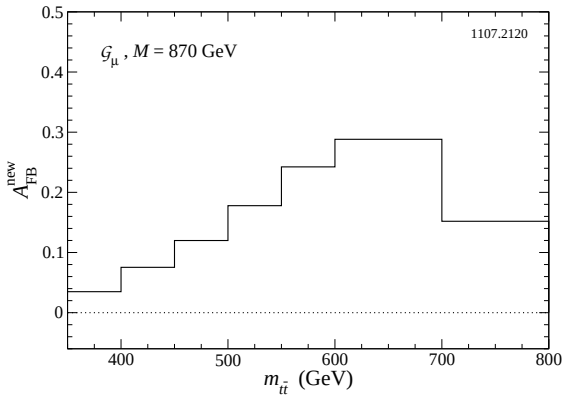
flat



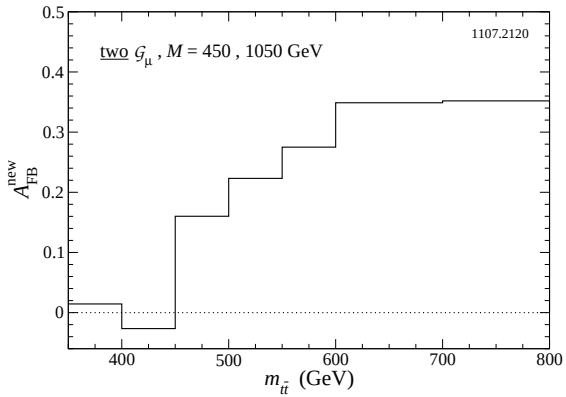
rising



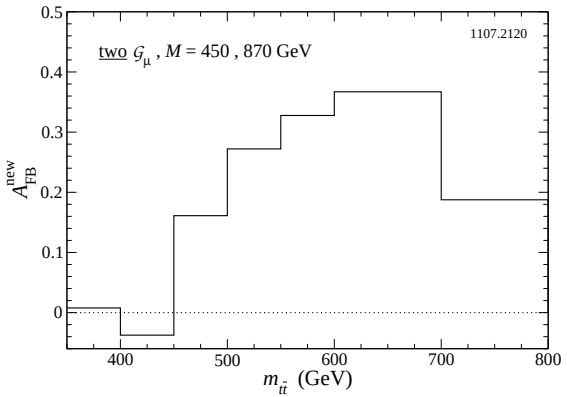
hill



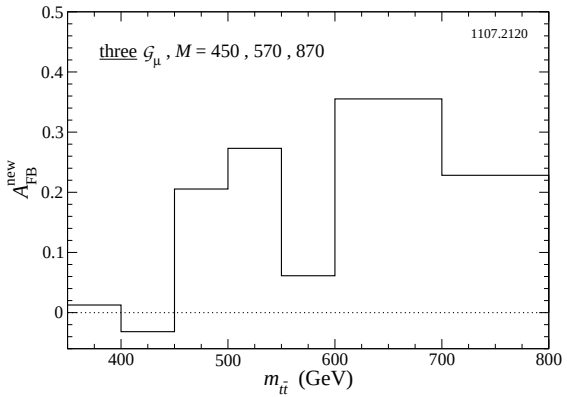
dip-rising



dip-hill



camel



Minutes of the meeting

- ★ Smoking guns not seen at LHC – unconclusive.
- ★ New effects in $t\bar{t}$ production searched. LHC data roughly agrees with SM, disfavouring some models.
- ★ New LHC constraints have prompted 2$^{\text{nd}}$ generation of models. They will be tested with precise measurements of $t\bar{t}$ production

Conclusion

A day may come when the courage of men fails, when we forsake our models and break all bonds with A_{FB}. But it is not this day.

ADDITIONAL SLIDES

The FB asymmetry at Tevatron

A_{FB} in $t\bar{t}$ CM frame is the top quark FB asymmetry in opening angle θ

$$A_{\mathrm{FB}} = \frac{N_t(\cos\theta > 0) - N_t(\cos\theta < 0)}{N_t(\cos\theta > 0) + N_t(\cos\theta < 0)}$$

where θ is the angle between the top quark momentum and the initial proton direction.

Also, since in CM frame $N_t(\cos\theta < 0) = N_{\bar{t}}(\cos\bar{\theta} > 0)$, it can be written as

$$A_{\mathrm{FB}} = \frac{N_t(\cos\theta > 0) - N_{\bar{t}}(\cos\bar{\theta} > 0)}{N_t(\cos\theta > 0) + N_{\bar{t}}(\cos\bar{\theta} > 0)}$$

that is, a charge asymmetry where the initial partons stay fixed

☞ do not confuse with C, charge conjugation symmetry !!!

The charge asymmetry at LHC

LHC is a pp collider, harder to define 'forward' and 'backward'

[but it can be done event by event, depending on boost of CM wrt LAB]

Alternatively, charge asymmetries can be defined:

- ★ t more forward than $\bar{t}$ at parton level
- ★ initial q larger momentum fraction than $\bar{q}$

→ tops larger (pseudo)rapidities in LAB frame

$$A_C = \frac{N(\Delta > 0) - N(\Delta < 0)}{N(\Delta > 0) + N(\Delta < 0)}$$

with $\Delta = |y_t| - |y_{\bar{t}}|$ or $\Delta = |\eta_t| - |\eta_{\bar{t}}|$ (taken by CMS)

Tree-level particles in $q\bar{q} \to t\bar{t}$

Colour:

$3 \otimes \bar{3} = 8 \oplus 1$

$3 \otimes 3 = 6 \oplus \bar{3}$

Isospin:

$2 \otimes 2 = 3 \oplus 1$

$2 \otimes 1 = 2$

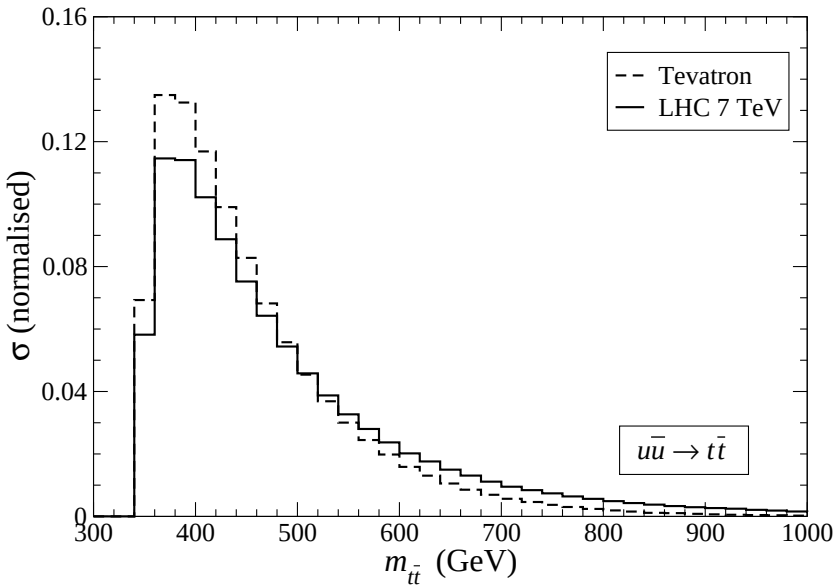
$1 \otimes 1 = 1$

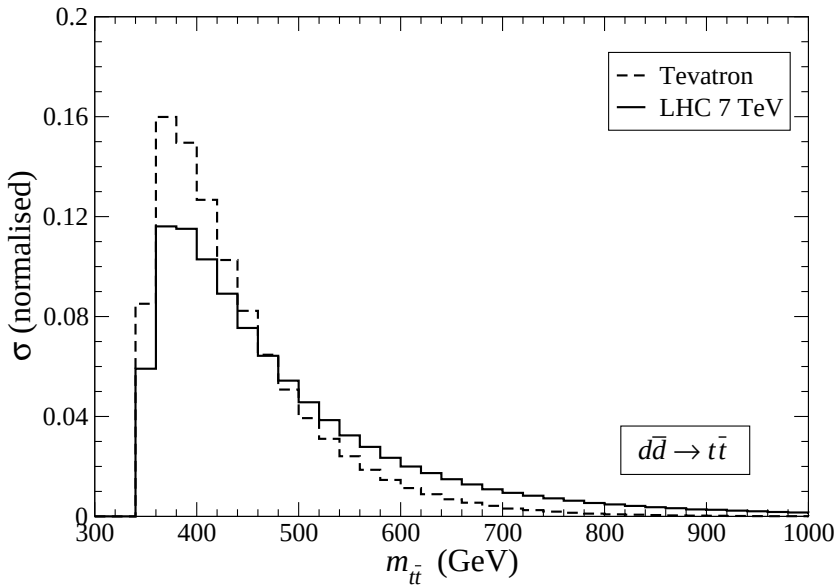
Hypercharge:

$\sum Y = 0$

Vectors		Scalars	
Label	Rep.	Label	Rep.
$\mathcal{B}_\mu$	$(1,1)_0$	ϕ	$(1,2)_{-\frac{1}{2}}$
$\mathcal{W}_\mu$	$(1,3)_0$	Φ	$(8,2)_{-\frac{1}{2}}$
$\mathcal{B}^1_\mu$	$(1,1)_1$	ω^1	$(3,1)_{-\frac{1}{3}}$
$\mathcal{G}_\mu$	$(8,1)_0$	Ω^1	$(\bar{6},1)_{-\frac{1}{3}}$
$\mathcal{H}_\mu$	$(8,3)_0$	ω^4	$(3,1)_{-\frac{4}{3}}$
$\mathcal{G}^1_\mu$	$(8,1)_1$	Ω^4	$(\bar{6},1)_{-\frac{4}{3}}$
$\mathcal{Q}^1_\mu$	$(3,2)_{\frac{1}{6}}$	σ	$(3,3)_{-\frac{1}{3}}$
$\mathcal{Q}^5_\mu$	$(3,2)_{-\frac{5}{6}}$	Σ	$(\bar{6},3)_{-\frac{1}{3}}$
$\mathcal{Y}^1_\mu$	$(\bar{6},2)_{\frac{1}{6}}$		
$\mathcal{Y}^5_\mu$	$(\bar{6},2)_{-\frac{5}{6}}$		

$t\bar{t}$ invariant mass distributions





CDF Camel profile