$A_{FB} \ met \ LHC$

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Status of $A_{FB}$: experiments vs theories

Tevatron: $A_{FB}$ !!!

Models: $Z', W', g', \ldots$

LHC:

predictions
Status of $A_{FB}$: experiments vs theories

- **Tevatron:** $A_{FB}$ !!!

- **Models:** $Z'$, $W'$, $g'$, ...

- **Predictions**

- **LHC:** SM !!!

**Explanations**

**Now:** constraints
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

$$A_{FB} = 0.158 \pm 0.075 \text{ (inclusive)} \quad \text{SM: 0.058 \ 1.3}\sigma$$
$$A_{FB} = 0.475 \pm 0.114 \ (m_{t\bar{t}} > 450 \text{ GeV}) \quad \text{SM: 0.088 \ 3.4}\sigma$$

07/2011
long awaited D0 measurement confirms inclusive but not high-mass $A_{FB}$
updated SM predictions reduce discrepancies

$$A_{FB} = 0.196 \pm 0.065 \text{ (inclusive)} \quad \text{SM: 0.0893 \ 1.6}\sigma$$
$$A_{FB} \sim 0.2 \ (m_{t\bar{t}} > 450 \text{ GeV}) \quad \text{SM: 0.139}$$
Timeline of models

AFB papers

Model flood

New trends

Most popular models

**s channel:**

\[ G_\mu \sim (8, 1)_0 \]

\[
\begin{align*}
0 & \quad 0809.3354, 0906.0604, 0911.2955, 1007.0243, 1011.6380, 1011.6557, \\
& \quad 1101.2902, 1101.5203, 1103.0956, 1104.1917, 1105.3158, 1105.3333, \\
& \quad 1106.0529, 1106.4054, 1107.0978, 1107.1473, 1107.2120, 1107.5769
\end{align*}
\]

**t channel:**

\[ Z' \sim (1, 1)_0 \]

\[
\begin{align*}
0 & \quad 0907.4112, 1101.4456, 1101.5625, 1102.0545, 1103.1266, 1103.4835, \\
& \quad 1104.1385, 1104.3139, 1106.5982, 1108.0350, 1108.1802
\end{align*}
\]

\[ W' \sim (1, 1)_1 \]

\[
\begin{align*}
0 & \quad 0908.2589, 1002.1048, 1003.3461, 1101.1445, 1101.5392, 1102.0279, \\
& \quad 1104.0083, 1105.4606
\end{align*}
\]

\[ \phi \sim (1, 2)_{-\frac{1}{2}} \]

\[
\begin{align*}
1104.4782, 1107.0841, 1107.4350, 1108.4005
\end{align*}
\]

**u channel:**

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

\[
\begin{align*}
0 & \quad 0911.3237, 0911.4875, 0912.0972, 1007.2604, 1102.3374, \\
& \quad 1102.4736, 1103.2757, 1108.4027
\end{align*}
\]

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

$0907.4112, 1101.4456, 1101.5625, 1102.0545, 1104.1385$

\[ \text{But for complex } Z': \text{ forget all this} \]

$1103.4835$
Excludes model parameter region consistent with $\sigma = 7.50 \pm 0.48$ pb, high-mass $A_{FB} = 0.475 \pm 0.114$

What if $A_{FB}$ not so large? (D0)
No smoke, no gun: no like-sign tops

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

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

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

$A_{FB}^{new} > 0$ 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 $A_{FB}^{\text{new}} \gtrsim 0.1$

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 $G_\mu$ !!!
\( t\bar{t} \) 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

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

$A_{FB}^{new}$ for $m_{t\bar{t}} > 450$ GeV

- $Z'$ tail $< 3 \times \text{SM}$
- $W'$ tail $< 3 \times \text{SM}$
- $\mu$ tail $< 3 \times \text{SM}$
- $\phi$ tail $< 3 \times \text{SM}$
- $\Omega^4$ tail $< 3 \times \text{SM}$
Constraints from $m_{t\bar{t}}$ tail \[ \sigma(m_{t\bar{t}} > 1 \text{ TeV}) \in 0.5 - 1.5 \times SM \]
Consequences of $t\bar{t}$ tail measurement theorists’ guess

1. $Z'$ models disfavoured
2. $W'$ models disfavoured
3. Heavy $s$-channel $G_\mu$ must be very heavy and couple strongly
   - Ugly model
4. Scalar $\phi$: 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**

![Flat profile](image)

$g_\mu$ below $t$ threshold

$m_t$ (GeV)

0
0.1
0.2
0.3
0.4
0.5

$A_{FB}^{new}$

$m_t$ (GeV)

400 500 600 700 800

**rising**

![Rising profile](image)

$g_\mu$, $M = 1050$ GeV

$m_t$ (GeV)

0
0.1
0.2
0.3
0.4
0.5

$A_{FB}^{new}$

$m_t$ (GeV)

400 500 600 700 800

**hill**

![Hill profile](image)

$g_\mu$, $M = 870$ GeV

$m_t$ (GeV)

0
0.1
0.2
0.3
0.4
0.5

$A_{FB}^{new}$

$m_t$ (GeV)

400 500 600 700 800

**dip-rising**

![Dip-rising profile](image)

Two $g_\mu$, $M = 450, 1050$ GeV

$m_t$ (GeV)

0
0.1
0.2
0.3
0.4
0.5

$A_{FB}^{new}$

$m_t$ (GeV)

400 500 600 700 800

**dip-hill**

![Dip-hill profile](image)

Two $g_\mu$, $M = 450, 870$ GeV

$m_t$ (GeV)

0
0.1
0.2
0.3
0.4
0.5

$A_{FB}^{new}$

$m_t$ (GeV)

400 500 600 700 800

**camel**

![Camel profile](image)

Three $g_\mu$, $M = 450, 570, 870$

$m_t$ (GeV)

0
0.1
0.2
0.3
0.4
0.5

$A_{FB}^{new}$

$m_t$ (GeV)

400 500 600 700 800
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\textsuperscript{nd} generation of models. They will be tested with precise measurements of $t\bar{t}$ production.
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 $\theta$

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

where $\theta$ 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

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

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 $\bar{q}$

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

with $\Delta = |y_t| - |y_{\bar{t}}|$ or $\Delta = |\eta_t| - |\eta_{\bar{t}}|$ (taken by CMS)
Tree-level particles in $q\bar{q} \rightarrow t\bar{t}$

**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:**

$\sum Y = 0$

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<thead>
<tr>
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<tbody>
<tr>
<td>$B_\mu$</td>
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<td>$\phi$</td>
<td>$(1, 2)_{-\frac{1}{2}}$</td>
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<tr>
<td>$W_\mu$</td>
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<td>$\Sigma$</td>
<td>$(\bar{6}, 3)_{-\frac{1}{3}}$</td>
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<td>$Y^1_\mu$</td>
<td>$(\bar{6}, 2)_{\frac{1}{6}}$</td>
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$\bar{t}t$ invariant mass distributions

![Graphs showing $\bar{u}u \rightarrow \bar{t}t$ and $d\bar{d} \rightarrow \bar{t}t$ distributions for Tevatron and LHC 7 TeV.]
CDF Camel profile

![Graph showing CDF Camel profile](image)

- Black line: data (+ lepton)
- Red line: data (- lepton)

**Axes:**
- Vertical axis: $A_{tt\bar{t}}^\text{t\bar{t}}(M)$
- Horizontal axis: $M_{tt\bar{t}}$ (GeV/c²)

**Data Points:**
- Data points are plotted at various points on the graph for different values of $M_{tt\bar{t}}$.

**Legend:**
- Black line with markers: data (+ lepton)
- Red line with markers: data (- lepton)

**Scale:**
- Y-axis scale ranges from -0.4 to 0.6
- X-axis scale ranges from 350 to 800 GeV/c²

**Additional Information:**
- J. A. Aguilar Saavedra (Univ. Granada)