Dynamical origin of A_{FB}^t and A_{FB}^ℓ correlation

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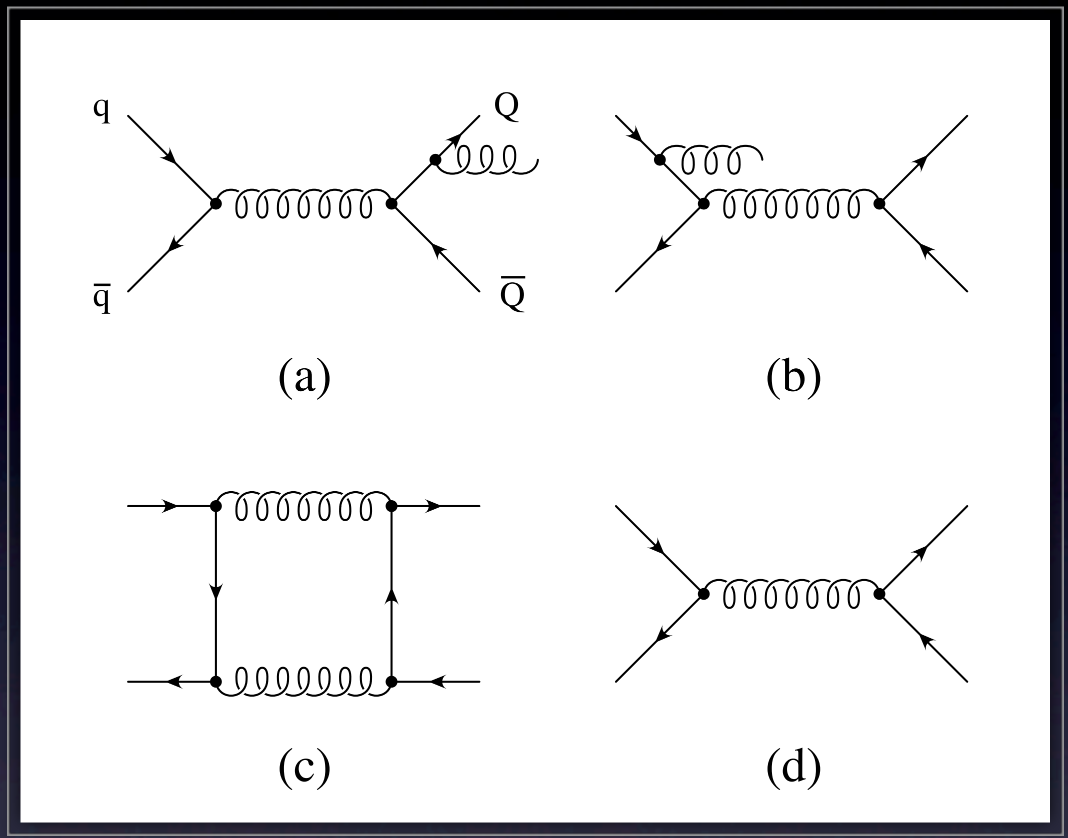
References:

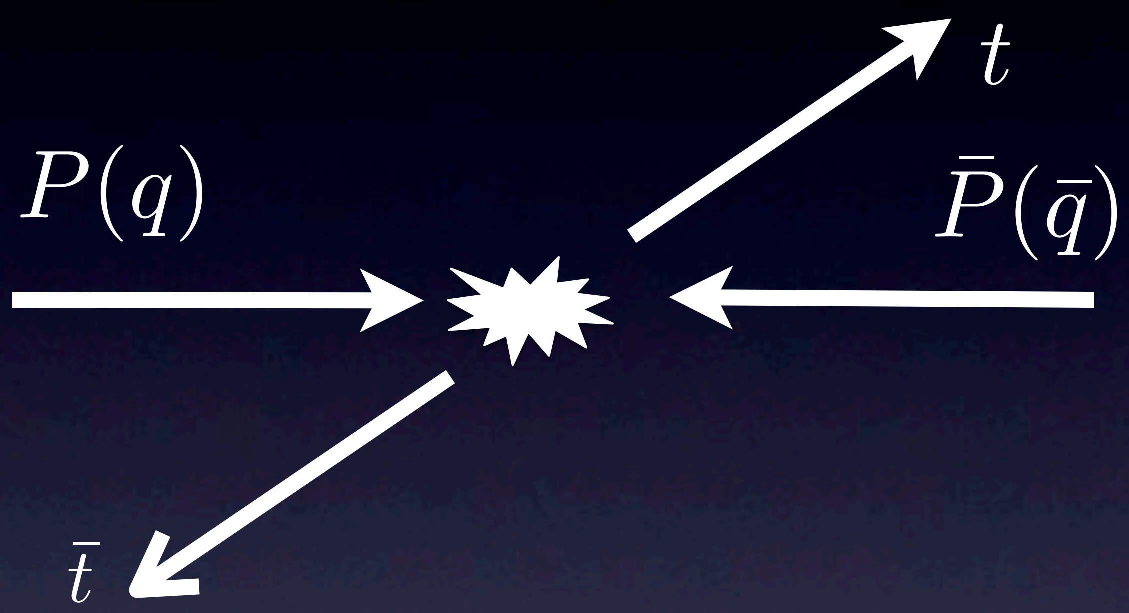
E. Berger, QHC, Chuan-Ren Chen, Jiang-Hao Yu and Hao Zhang, arXiv:1111.3641

Workshop on LHC and Dark Matter Physics @ SJTU Nov 27, 2011

Top-quark F-B asymmetry in the SM

- A charge asymmetry arises at NLO





Top quarks are produced along the direction of the incoming quark

$$A^{p\bar{p}} = \frac{N_t(y>0) - N_{\bar{t}}(y>0)}{N_t(y>0) + N_{\bar{t}}(y>0)} = 0.051(6)$$

$$A^{t\bar{t}} = \frac{N(\Delta y>0) - N(\Delta y<0)}{N(\Delta y>0) + N(\Delta y<0)} = 0.078(9) \quad \Delta y = y_t - y_{\bar{t}}$$

Timeline of top-quark A_{FB}

SM theo. Prediction

Kuhn, Rodrigo
hep-ph/9802268
SM NLO QCD
$A^t_{FB} = 5\%$

Brown, Ellis, Rainwater
hep-ph/0509267
Collider simulation of *tt+0(1)j*
Measuring AFB is
very challenging

Dittmaier, Uwer, Weinzierl
hep-ph/0703120
NLO QCD corr. to ttbar+j

Almeida, Sterman, Vogalsang
0805.1885
NLL Threshold resum.
Asymmetry is robust

Ahrens, Ferroglia, Neubert,
Pecjak, Li Lin Yang,
1003.5827
SCET NNLL

Melnikov, Schulze
1004.3284
Confirm Dittmaier et al

1998 — 2005 — 2007 — 2008 — 2010 — 2011

Exp. Measurements

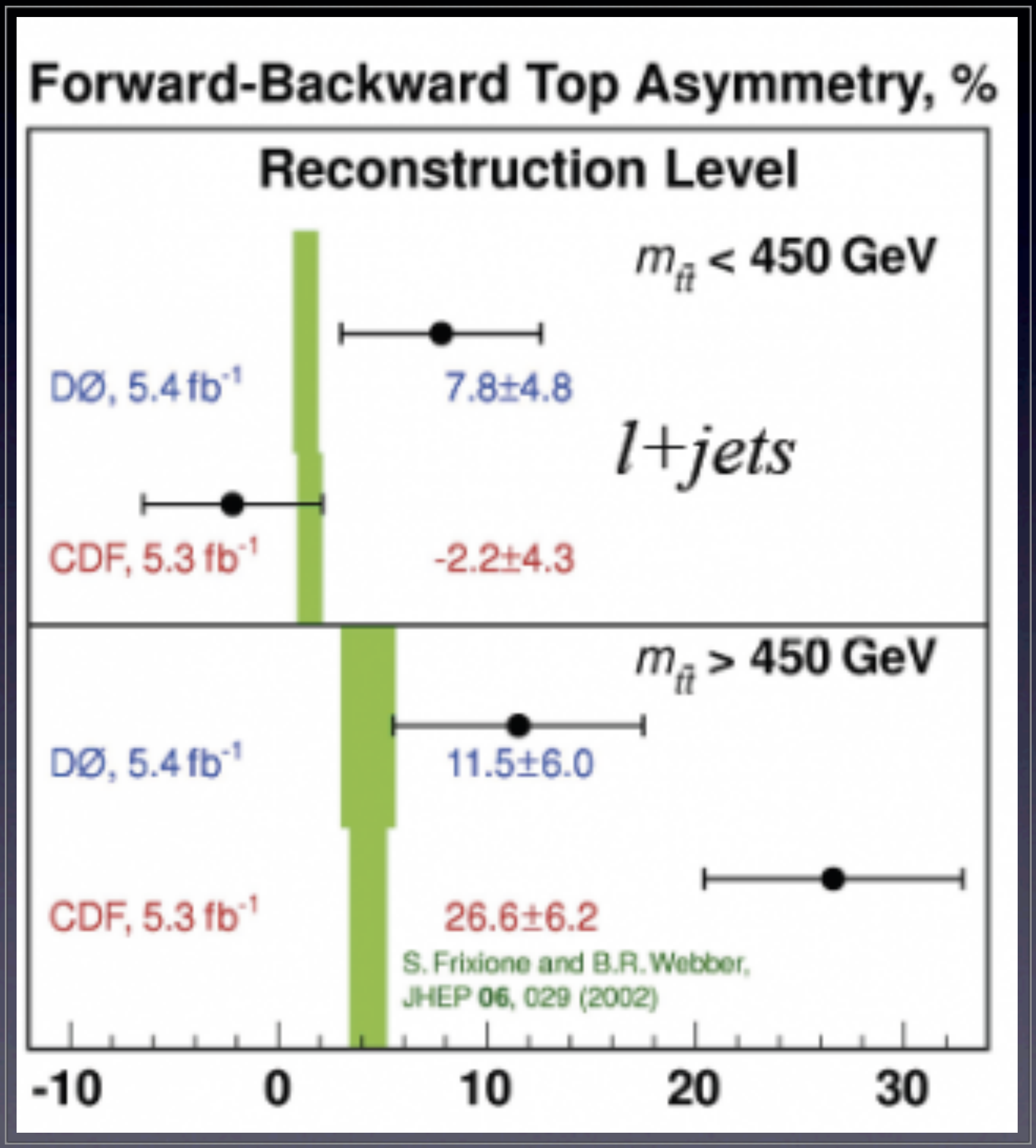
D0 (1.9 fb^{-1})
0712.0851
uncorrected
$A_{FB} = [12 \pm 8 \pm 1]\%$

CDF (1.9 fb^{-1})
0806.2472
$A_{FB} = [24 \pm 14]\%$
Consistent with SM

CDF (5.3fb^{-1})
1101.0034
$A_{FB} = 0.475 \pm 0.114$
for $m_{t\bar{t}} \geq 450$ GeV

D0 (5.4fb^{-1})
1107.4995
$A^t_{FB} = [19.6 \pm 6.5]\%$
$A^\ell_{FB} = [15.2 \pm 4.0]\%$

A^{ℓ}_{FB} versus A^{t}_{FB}



D0: $A^{t}_{FB} = 0.196 \pm 0.065$

$A^{\ell}_{FB} = 0.152 \pm 0.040$

$$\left.\frac{A^{\ell}_{FB}}{A^{t}_{FB}}\right|_{\rm D0} \sim \frac{3}{4}$$

SM: $A^{t}_{FB} = 0.051 \pm 0.001$

$A^{\ell}_{FB} = 0.021 \pm 0.001$

$$\left.\frac{A^{\ell}_{FB}}{A^{t}_{FB}}\right|_{\rm SM} \sim \frac{1}{2}$$

Bernreuther, Zong-Guo Si, arXiv:1003.3926

Top-quark: king of the SM

- Large mass: 173 GeV
- Short lifetime:

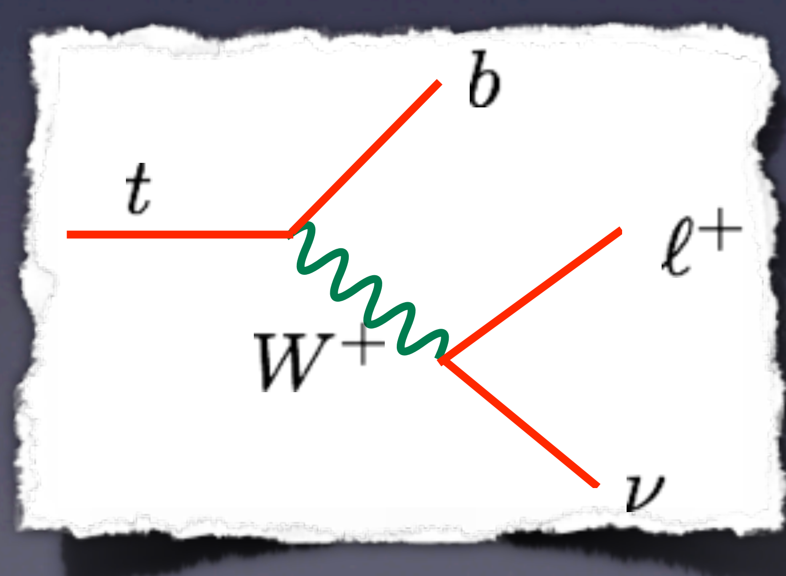
$\frac{1}{m_t}$ 5×10^{-27} s

$\frac{1}{\Gamma_t}$ 5×10^{-25} s

$\frac{1}{\Lambda_{QCD}}$ 3×10^{-24} s

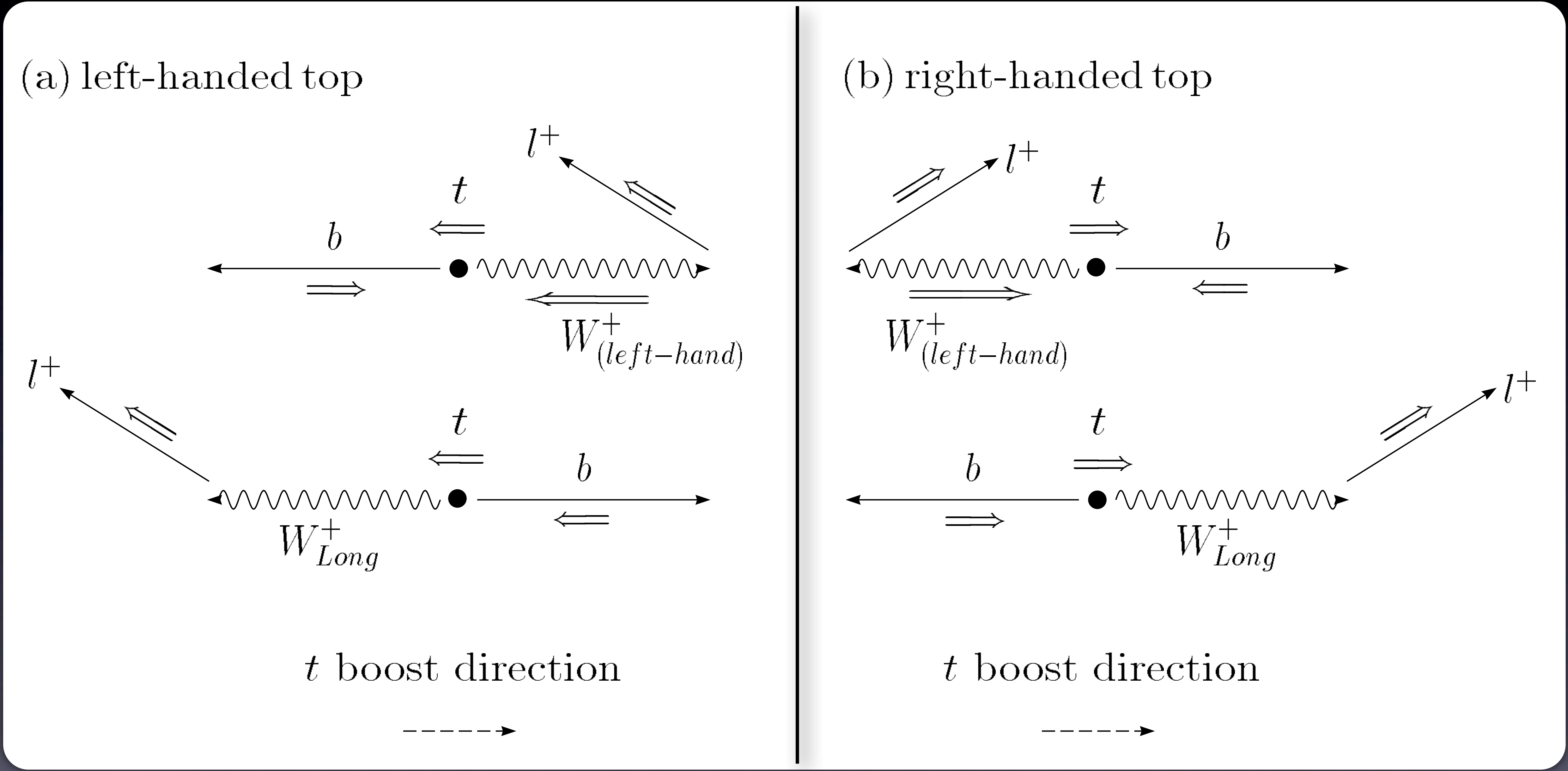
- "bare" quark:

  spin info well kept among its decay products



Top-quark leptonic decay

- Charged lepton: top-quark spin analyzer



The charged-lepton tends to follow the top-quark spin direction.

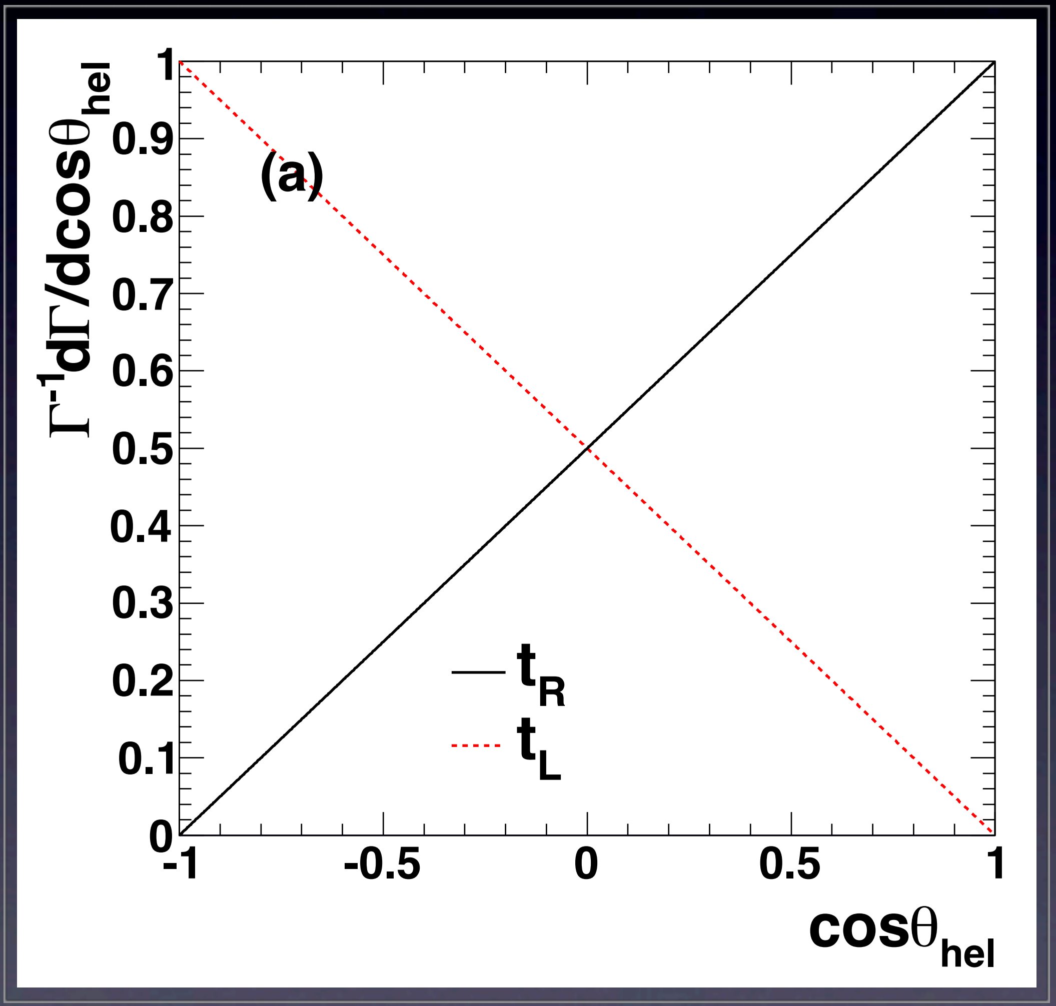
Charged lepton distribution

- In top-quark rest frame

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{\mathrm{hel}}} = \frac{1+\lambda_t\cos\theta_{\mathrm{hel}}}{2}$$

$\lambda_t = +$ right-handed

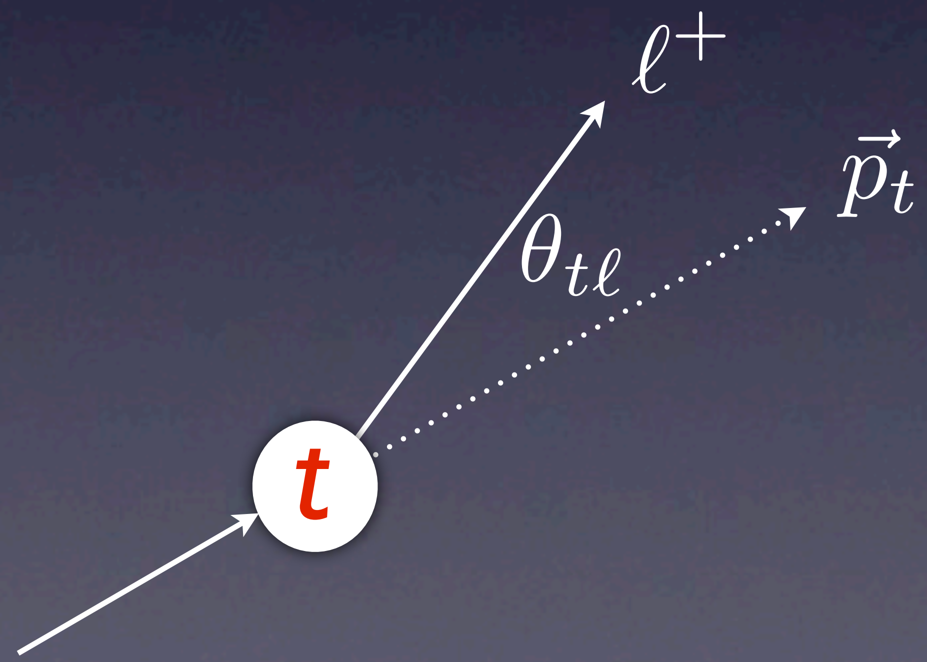
$\lambda_t = -$ left-handed

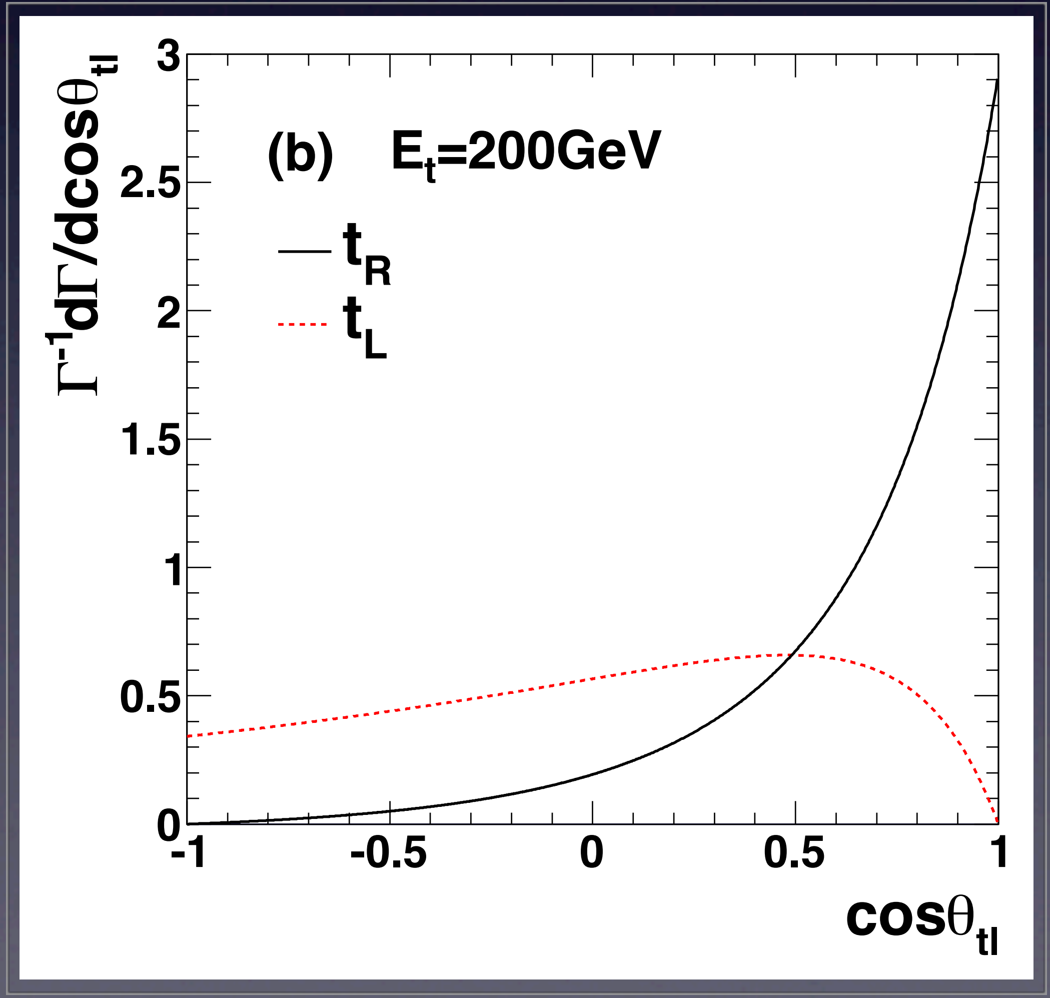


Charged lepton distribution

- In the c.m. frame

$$\frac{d\Gamma}{\Gamma d\cos\theta_{t\ell}} = \frac{1-\beta\cos\theta_{t\ell}+\lambda_t\left(\cos\theta_{t\ell}-\beta\right)}{2\gamma^2\left(1-\beta\cos\theta_{t\ell}\right)^3}$$



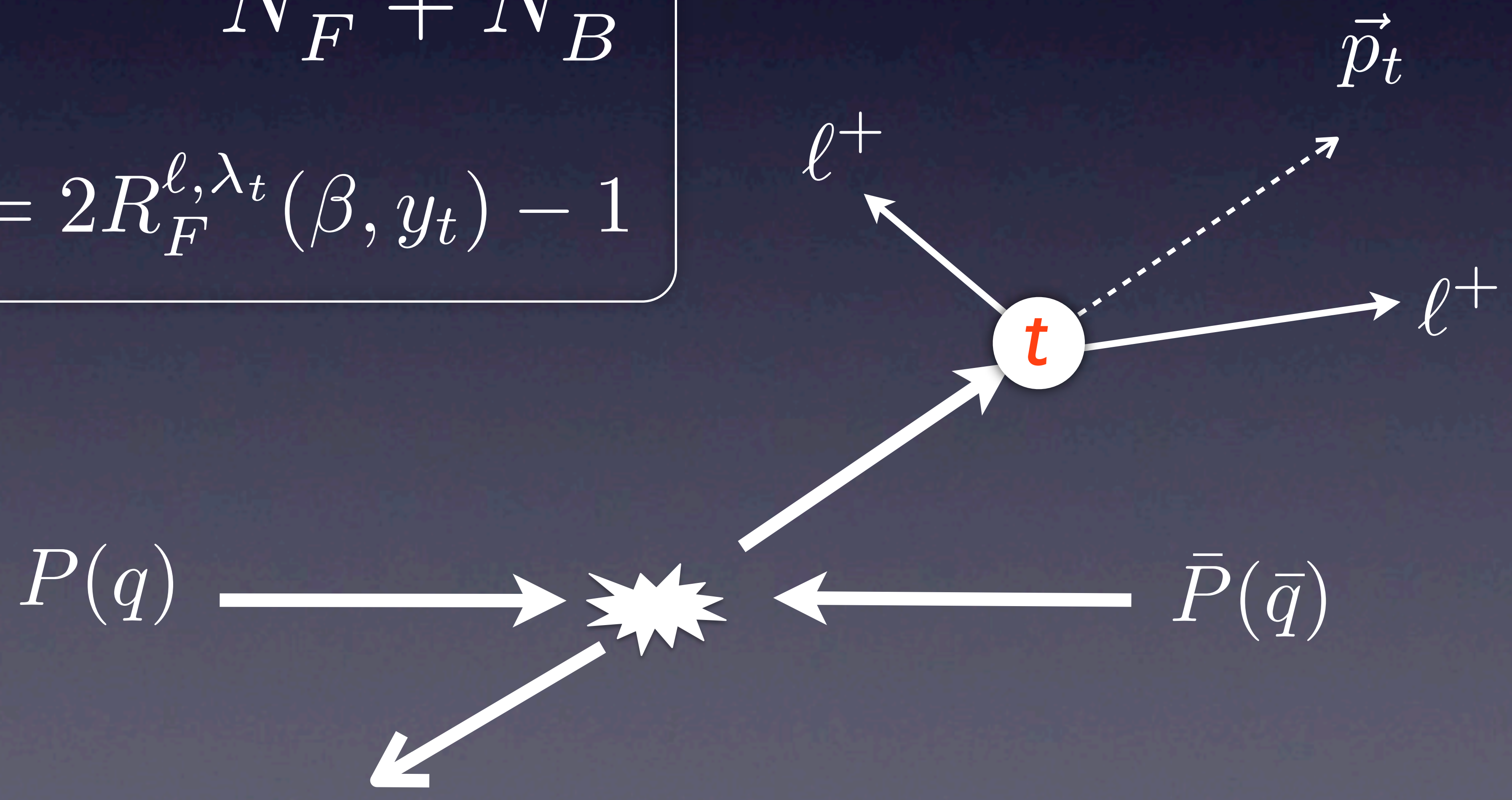


A^{ℓ}_{FB} dependence on top kinematics

- Possibility of lepton in the forward region of detector for a top-quark (β , y_t , λ_t)

$$R_F^{\ell,\ \lambda_t}(\beta, y_t) = \frac{N_F^{\ell}}{N_F^{\ell} + N_B^{\ell}}$$

$$A_{FB}^{\ell,\lambda_t}(\beta, y_t) = 2R_F^{\ell,\lambda_t}(\beta, y_t) - 1$$



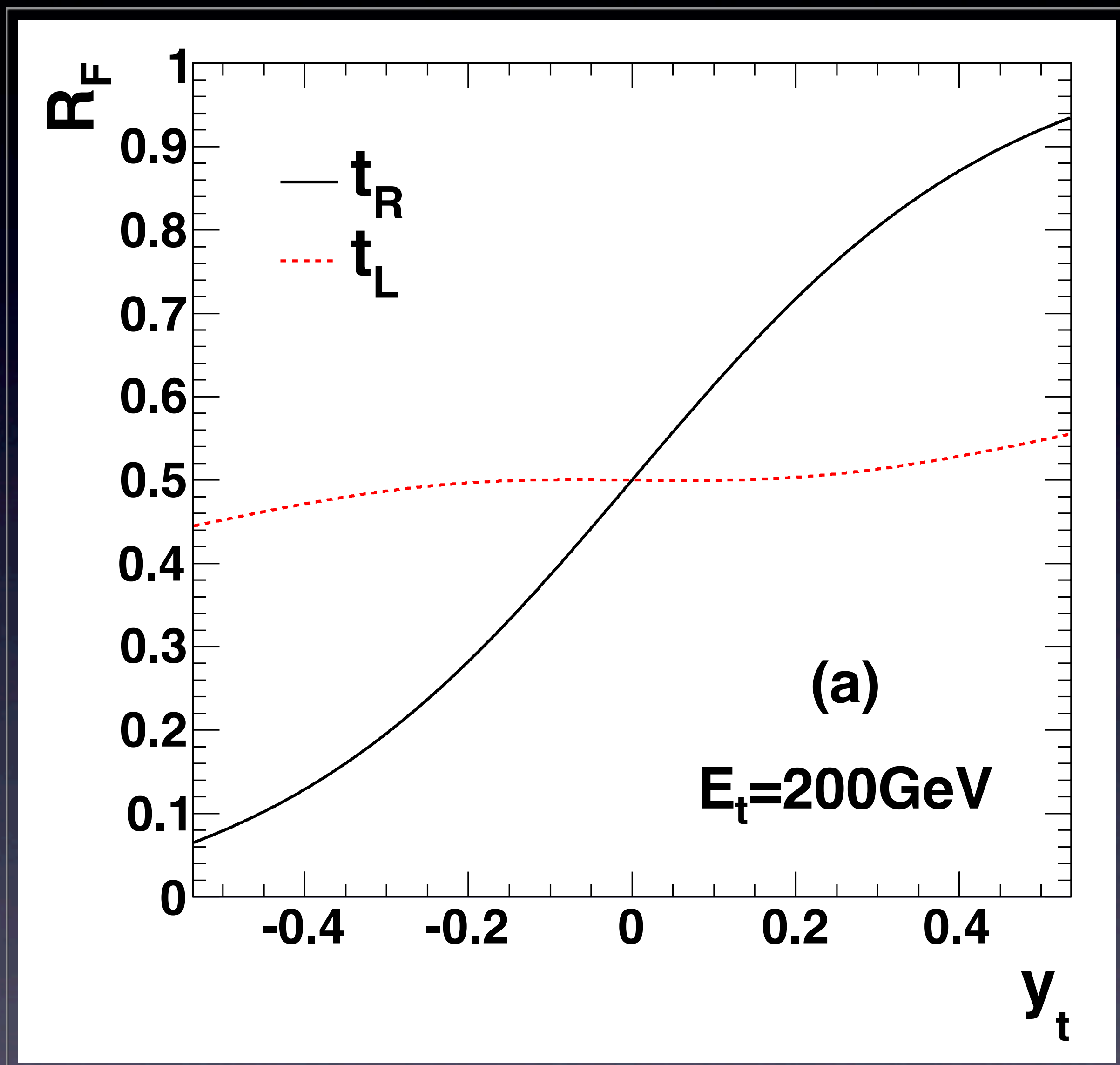
It is easy to show ...

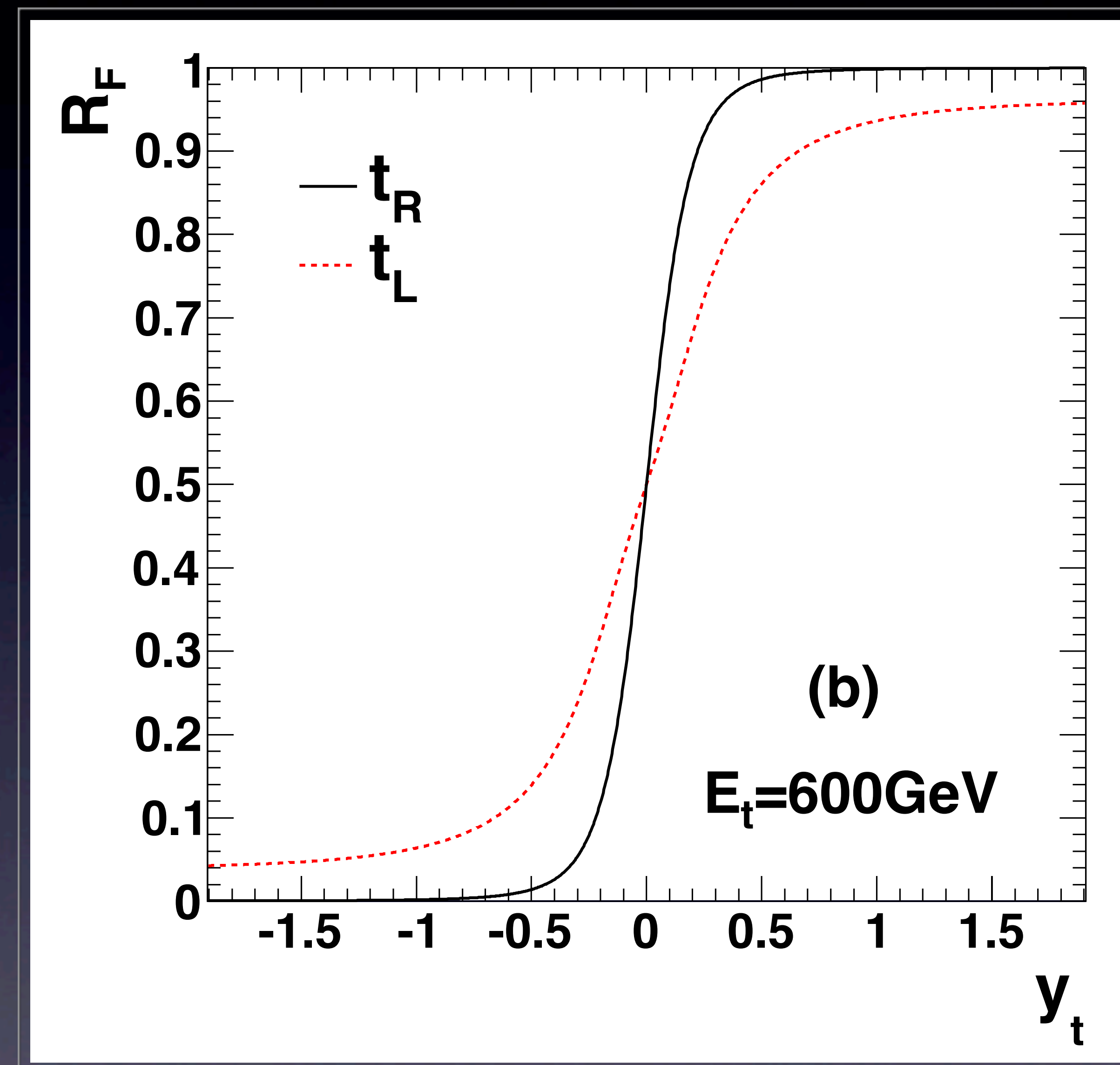
- Possibility of lepton in the forward region of detector for a top-quark (β, y_t , λ_t)

$$R_F^{\ell,\lambda_t}(\beta, y_t)$$

$$= \begin{cases} \dfrac{1}{2} + \dfrac{1}{2\left(1+\gamma^{-2}\coth^2 y_t\right)^{1/2}} + \dfrac{\lambda_t \coth^2 y_t}{4\beta\gamma^2\left(1+\gamma^{-2}\coth^2 y_t\right)^{3/2}}, & (y_t > 0) \\ \dfrac{1}{2} - \dfrac{1}{2\left(1+\gamma^{-2}\coth^2 y_t\right)^{1/2}} - \dfrac{\lambda_t \coth^2 y_t}{4\beta\gamma^2\left(1+\gamma^{-2}\coth^2 y_t\right)^{3/2}}, & (y_t < 0) \end{cases}$$

A^{ℓ}_{FB} dependence on top kinematics

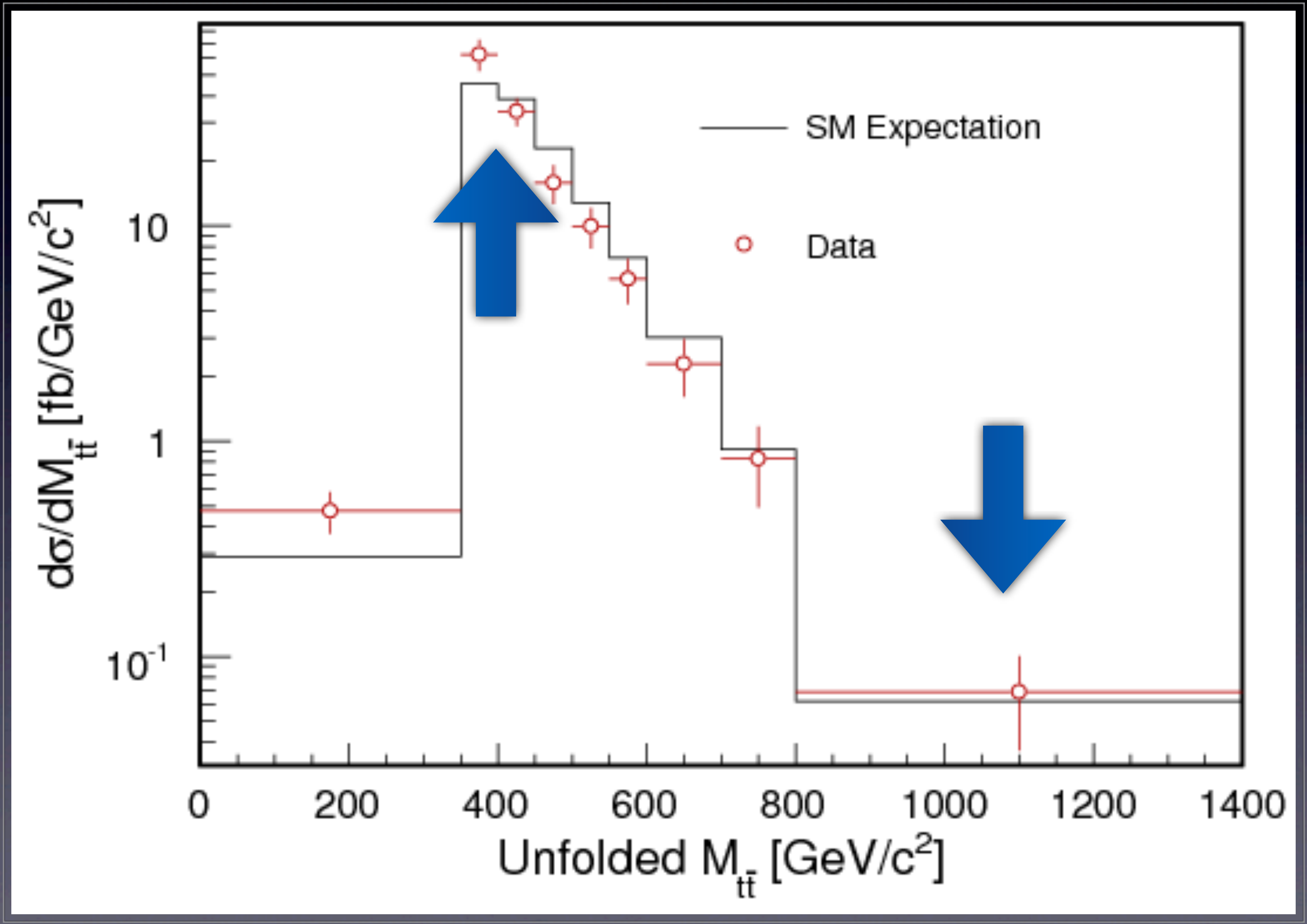




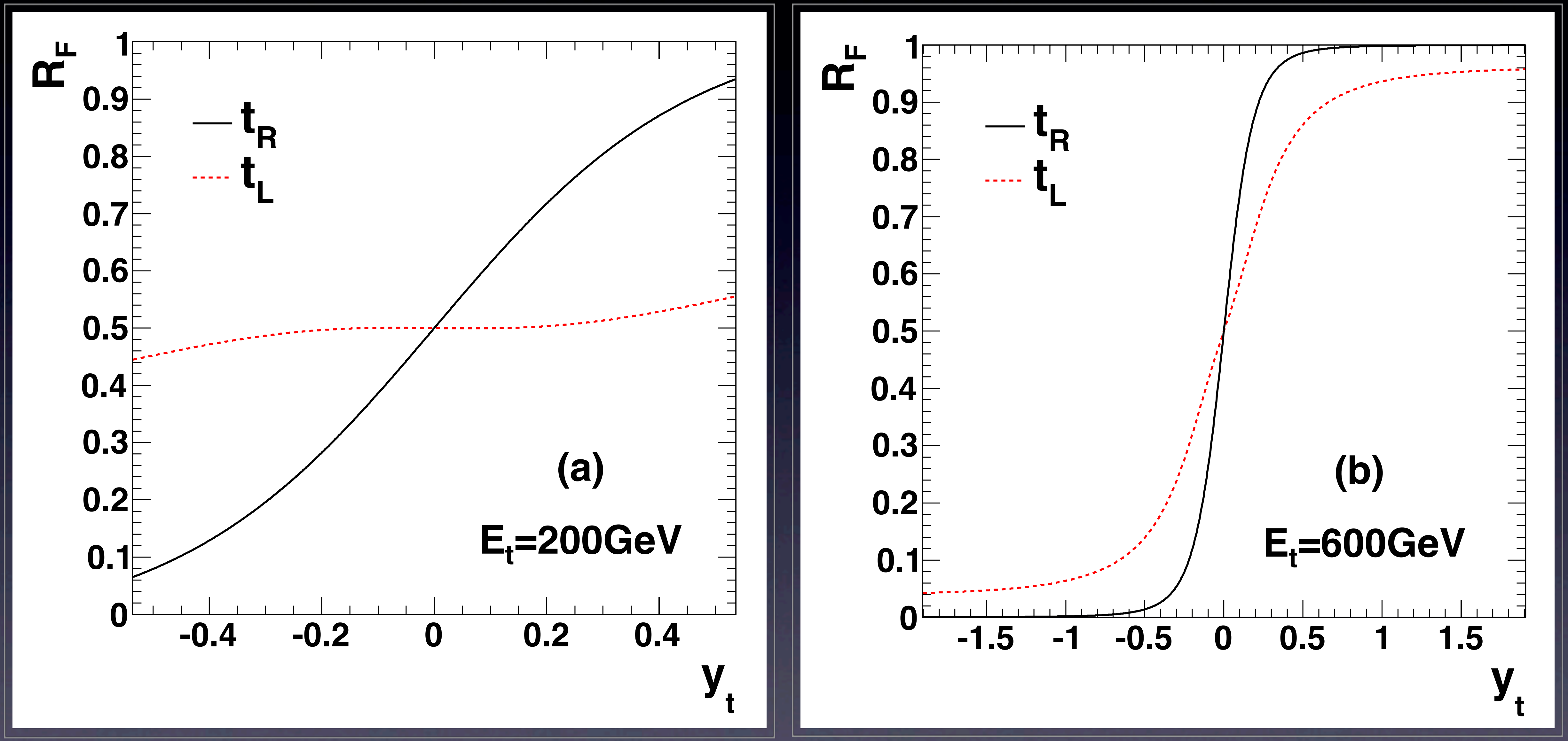
$$A_{FB}^{\ell,\lambda_t}(\beta, y_t) = 2R_F^{\ell,\lambda_t}(\beta, y_t) - 1$$

Invariant mass spectrum of top quark pair

CDF, Phys.Rev.Lett. 102 (2009) 222003

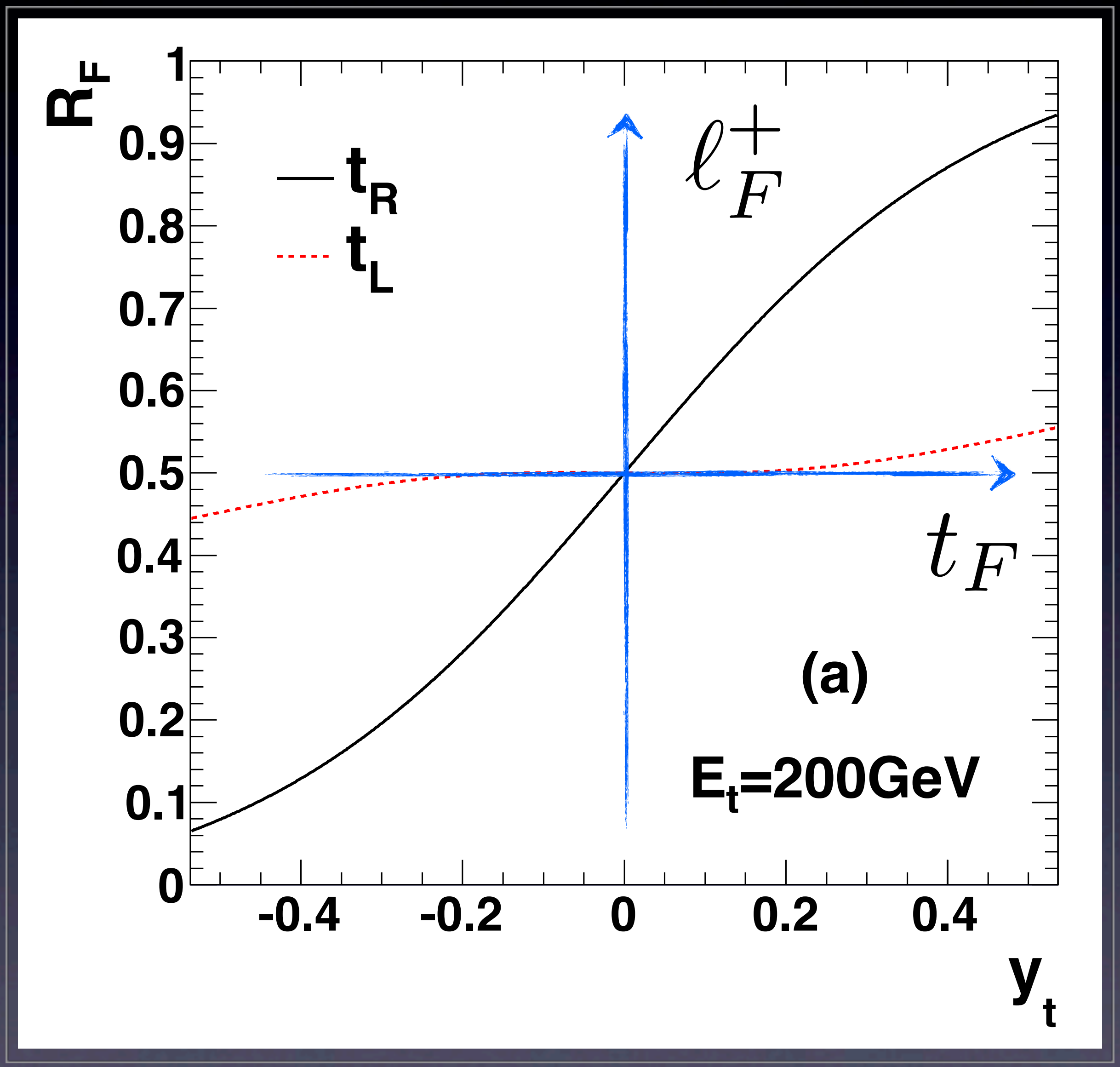


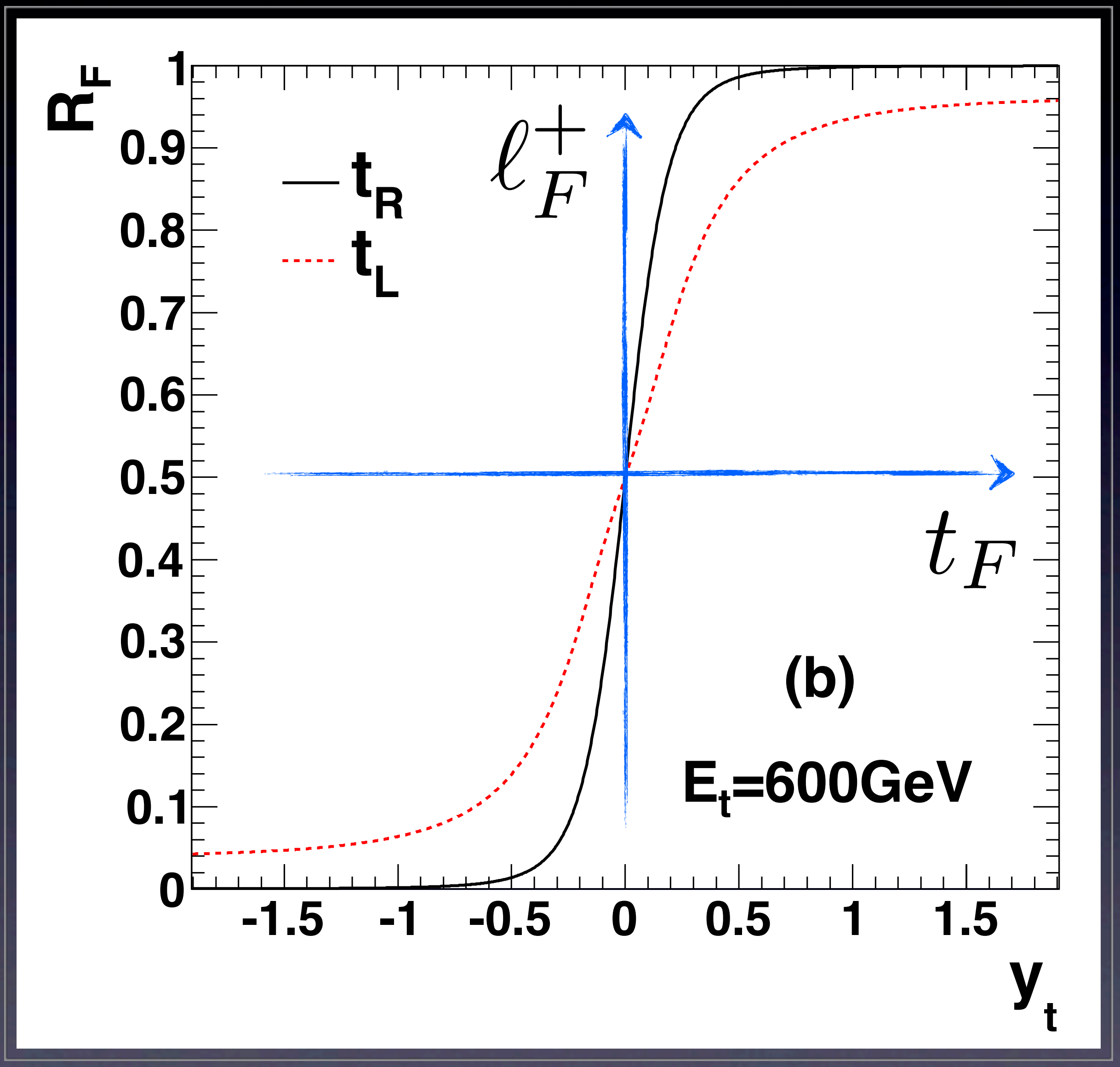
A^{ℓ}_{FB} dependence on top kinematics



$$A^{\ell,\lambda_t}_{FB}(\beta, y_t) = 2R^{\ell,\lambda_t}_F(\beta, y_t) - 1$$

A^{ℓ}_{FB} dependence on top kinematics





$$A^{\ell,\lambda_t}_{FB}(\beta, y_t) = 2R^{\ell,\lambda_t}_F(\beta, y_t) - 1$$

A_{FB}^{t} and A_{FB}^{ℓ} correlation

- When $R_F \sim \mathrm{constant}$ ($\mathcal{R}_C^{t_L}, \mathcal{R}_C^{t_R}$)

$$A_{FB}^{\ell} \approx \rho_{t_L} A_{FB}^{t_L} \times \left(2\mathcal{R}_C^{t_L} - 1\right)$$

$$+\rho_{t_R} A_{FB}^{t_R} \times \left(2\mathcal{R}_C^{t_R} - 1\right)$$

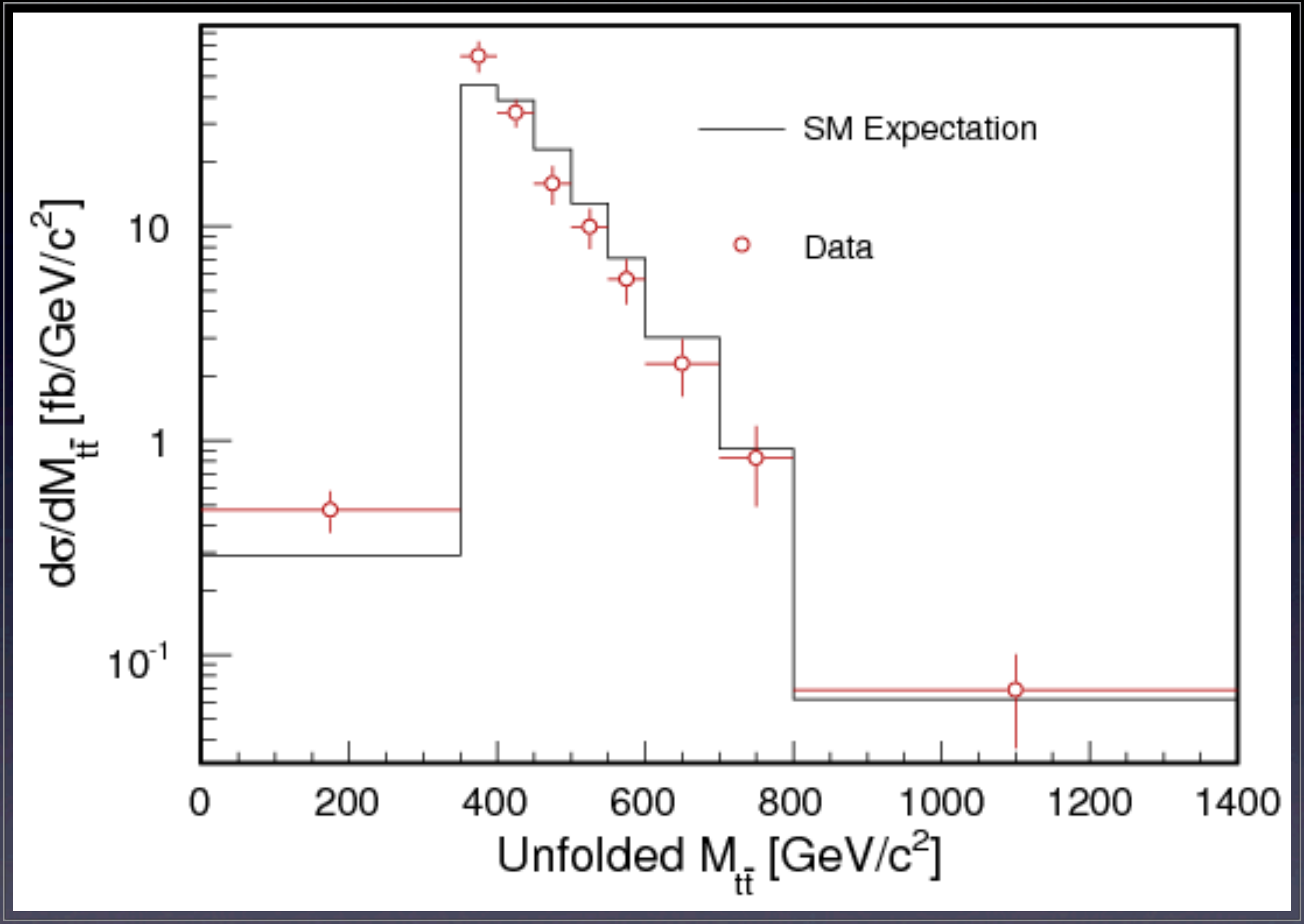
$$A_{FB}^{t} \approx \left[\rho_{t_L}\ A_{FB}^{t_L} + \rho_{t_R}\ A_{FB}^{t_R}\right]$$

$$\rho_{\lambda_t} = \frac{N^{\lambda_t}}{N_{\mathrm{tot}}}$$

- The simple approximation helps in understanding the NP prediction obtained from a complete numerical calculation.

Invariant mass spectrum of top quark pair

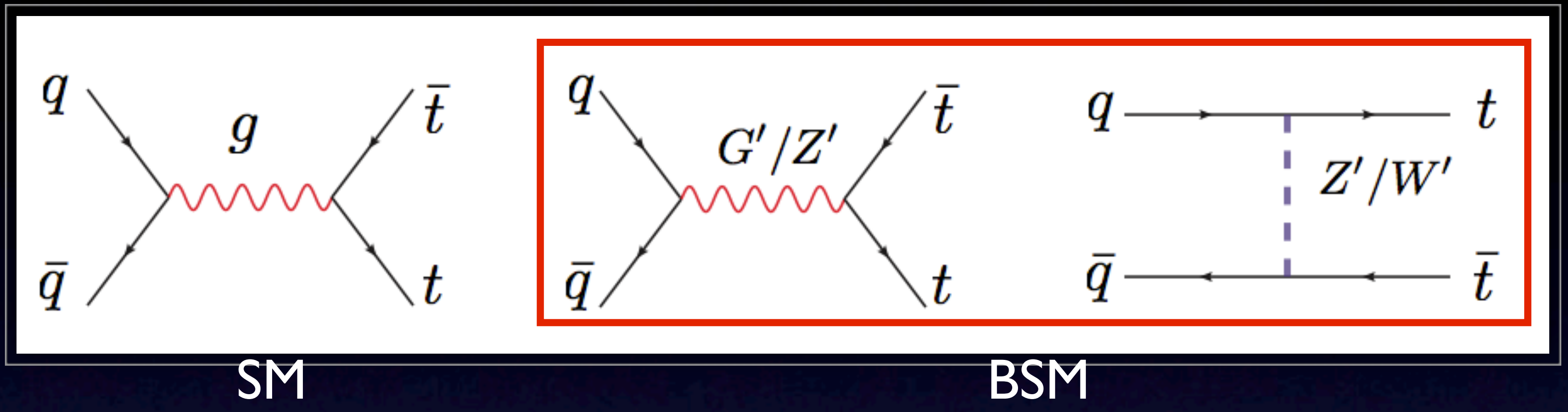
CDF, Phys.Rev.Lett. 102 (2009) 222003



It provides upper bounds on NP resonance.
The large bin (800GeV-1400GeV) is
the most sensitive to a heavy resonance

New physics models

NP models are divided into two classes



- *s*-channel: extra octet vector gluon (axigluon is the best)

  Small couplings to the first two generations: dijet constraints at 7 TeV
  Large couplings to third generation: to generate large A_{FB}
  Heavy resonances: ttbar invariant mass spectrum
  Very broad width: to interfere with the SM channel

- *t*-channel: flavor changing interaction

  color singlet: Z'-u-t (ϕ-u-t)
  W'$^+$-d-t (ϕ$^+$-d-t)

  color sextet or triplet

Timeline of A_{FB}^t and NP models

s-channel

Antunan, Kuhn, Rodrigo
Axigluon
0709.1652

Ferrario, Rodrigo
Axigluon
0809.3353

Djouadi, Moreau, Richard, singh
KK Gluon
0906.0604

Ferrario, Rodrigo
chiral G'
0906.5541

Frampton, Shu, Wang
Axigluon
0911.2955

EFT

Jung, Ko, Lee, Nam
EFT
0912.1105

QHC et al
Effective coupling
(G', Z', W', H^0, H^+)
1003.3461

2007, 2008 → 2009 → 2010, 2011

t-channel

Jung, Murayama, Pierce, Wells
FCNC Z-prime
0907.4112

Cheung, Keung, Yuan
FC W-prime
0908.2589

Shu, Tait, Wang
Color Sextet/triplet scalar
0911.3237

Arhrib, Benbrik, Chen
Color Sextet/triplet scalar
0911.4875

J. Cao, Heng, Wu, Yang
$\not{R}$-SUSY and TC2
0912.1447

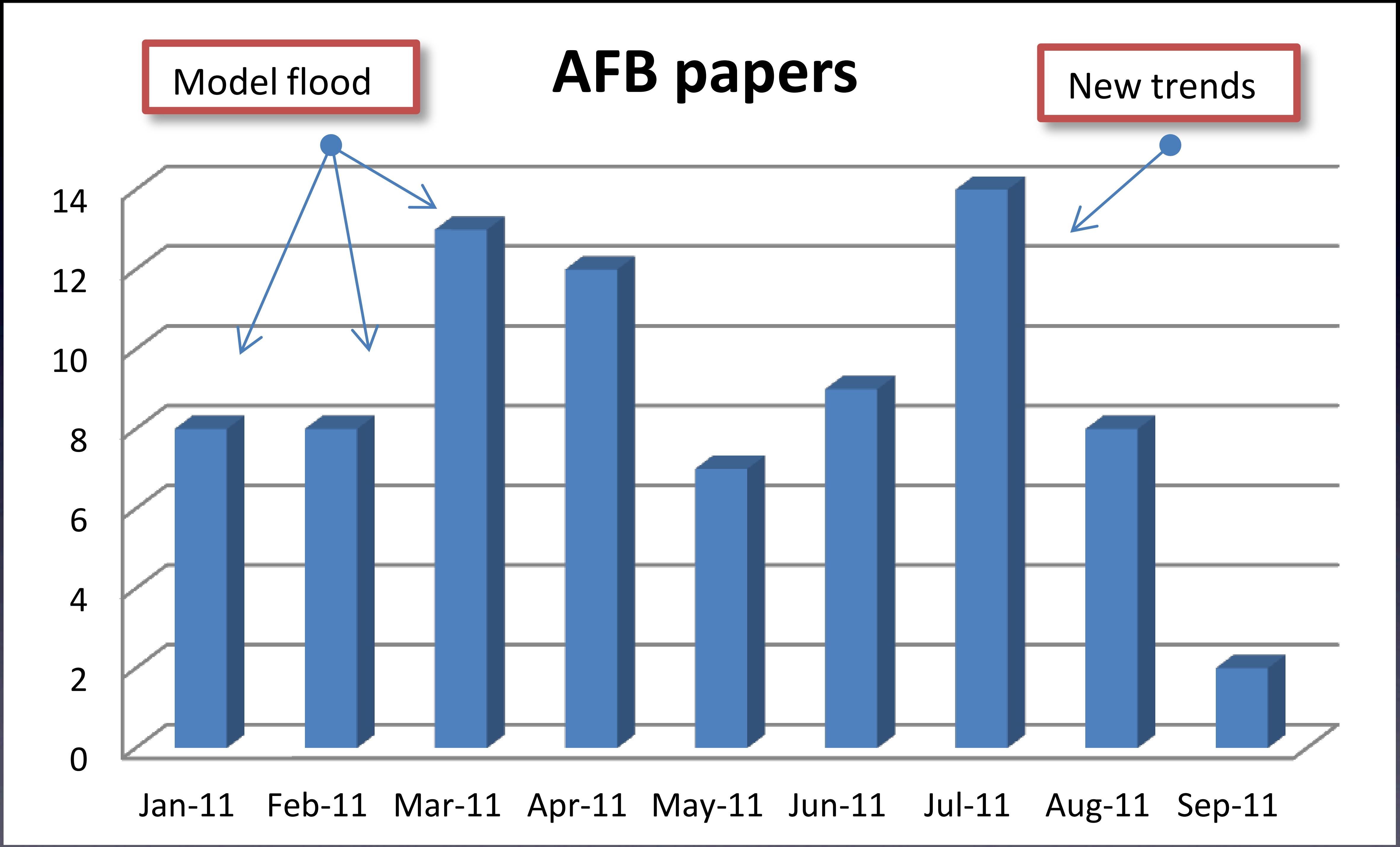
NLO QCD

Xiao, Wang, Zhu,
NLO QCD to Z-prime
1006.2510

Yan, Wang, Shao, Li
NLO QCD to W-prime
1110.6684

Shao, Li, et al
NLO QCD to EFT
1107.4012

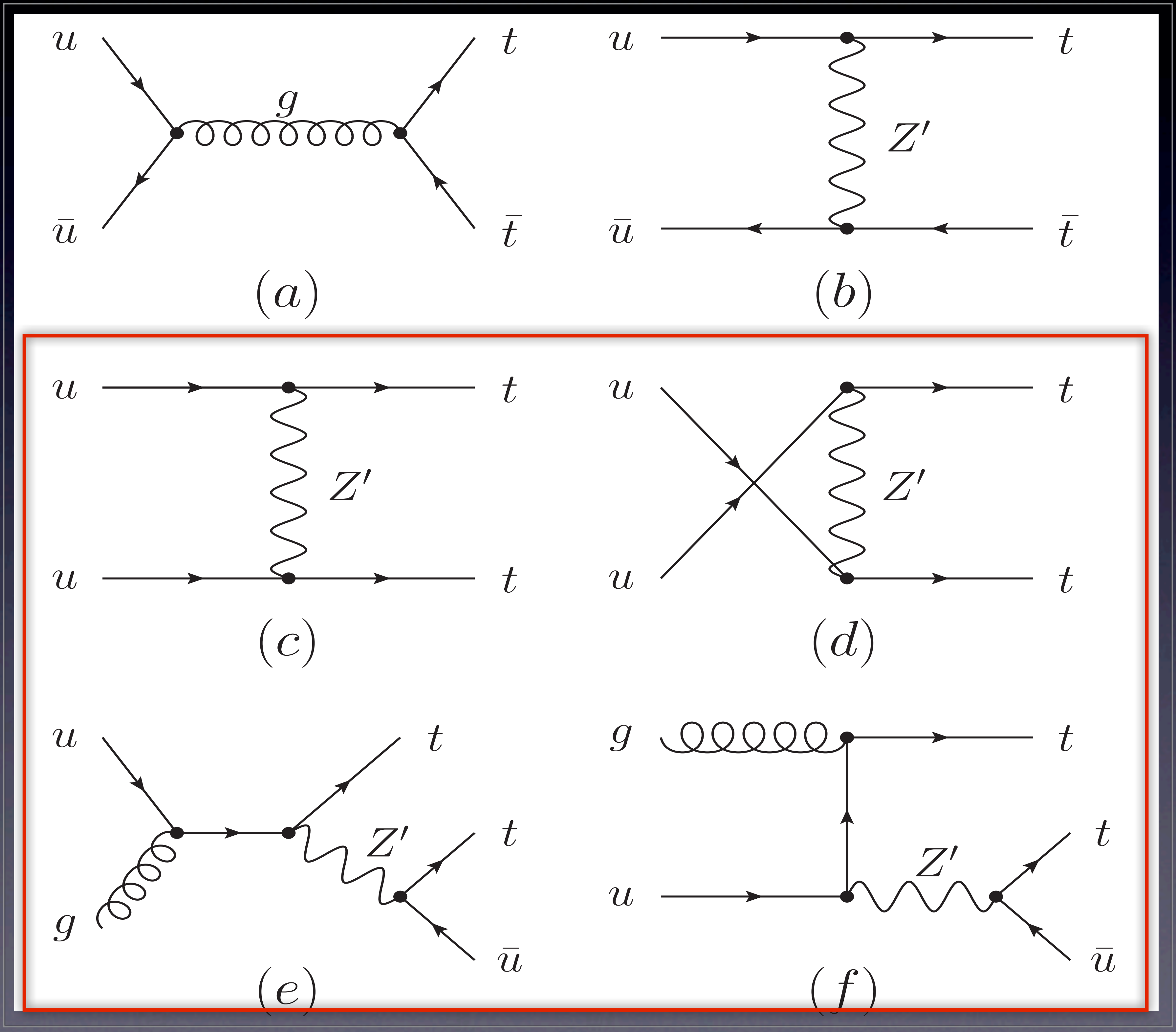
Timeline of A^t_{FB} and NP models



Adopted from J.A. Aguilar Saavedra's talk at TOP 2011, Sept. 2011

FCNC Z-prime: *t*-channel

- produce same-sign top-quark pair at the LHC



J. Cao et al
hep-ph/0703308
hep-ph/0409334

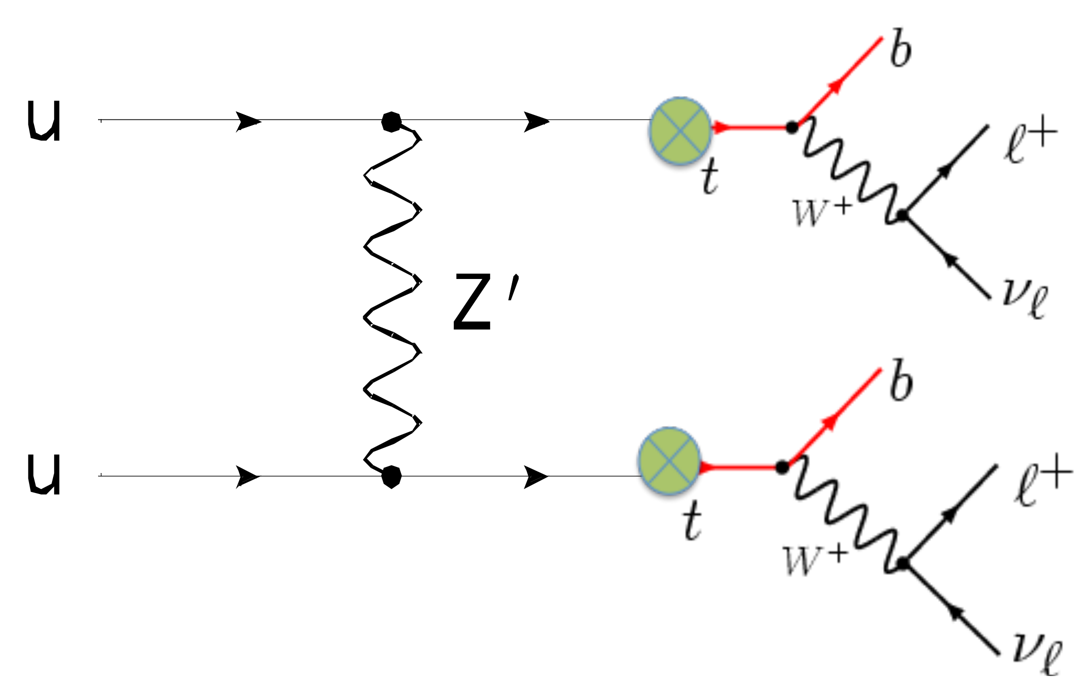
Same-sign top pair

t t + jet

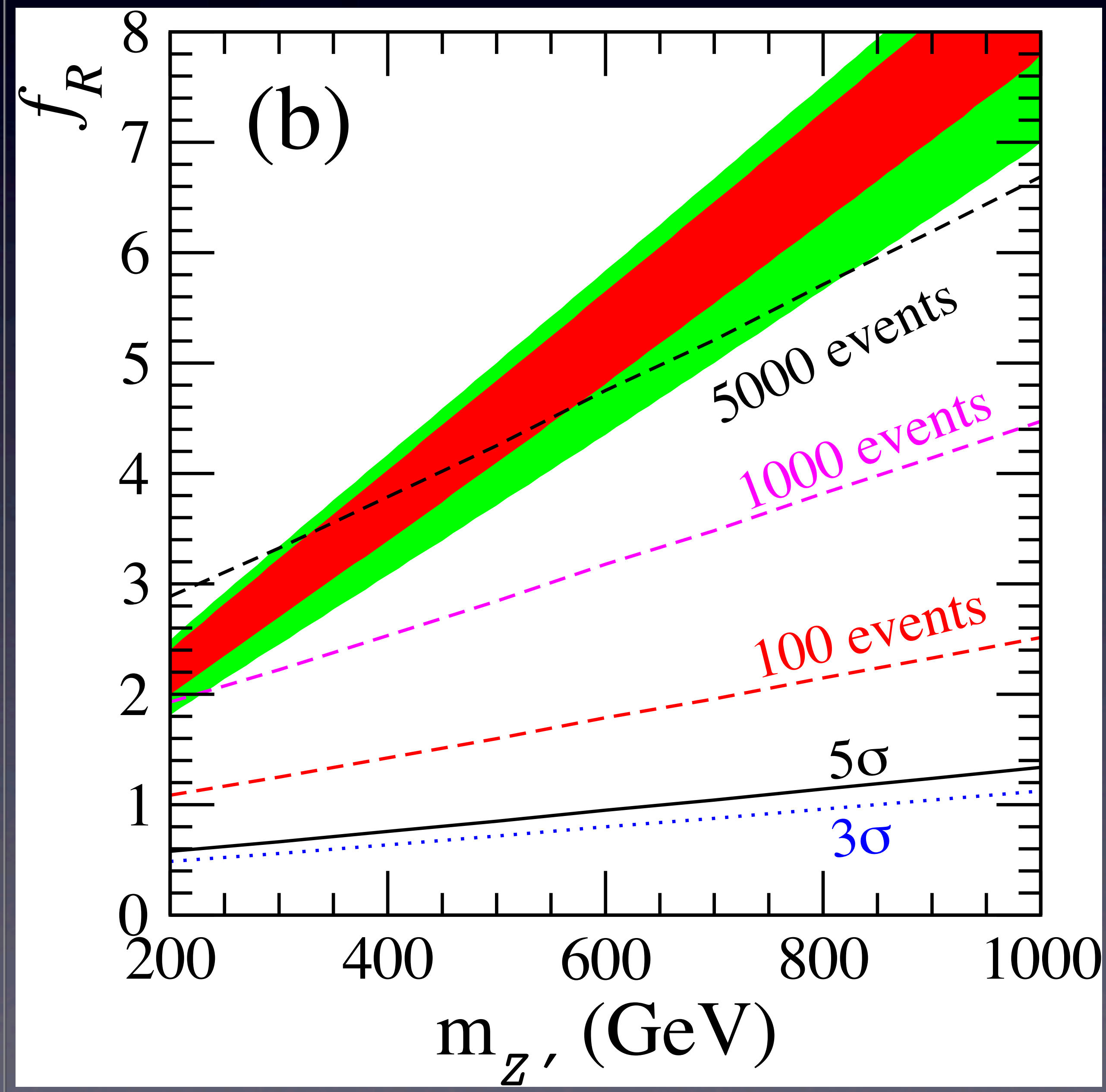
FCNC Z-prime: *t*-channel

- produce same-sign top-quark pair at the LHC

Ed Berger, QHC, Chuan-Ren Chen, Chong Sheng Li, Hao Zhang,
Phys. Rev. Lett. 106 (2011) 201801, arxiv:1101.5625



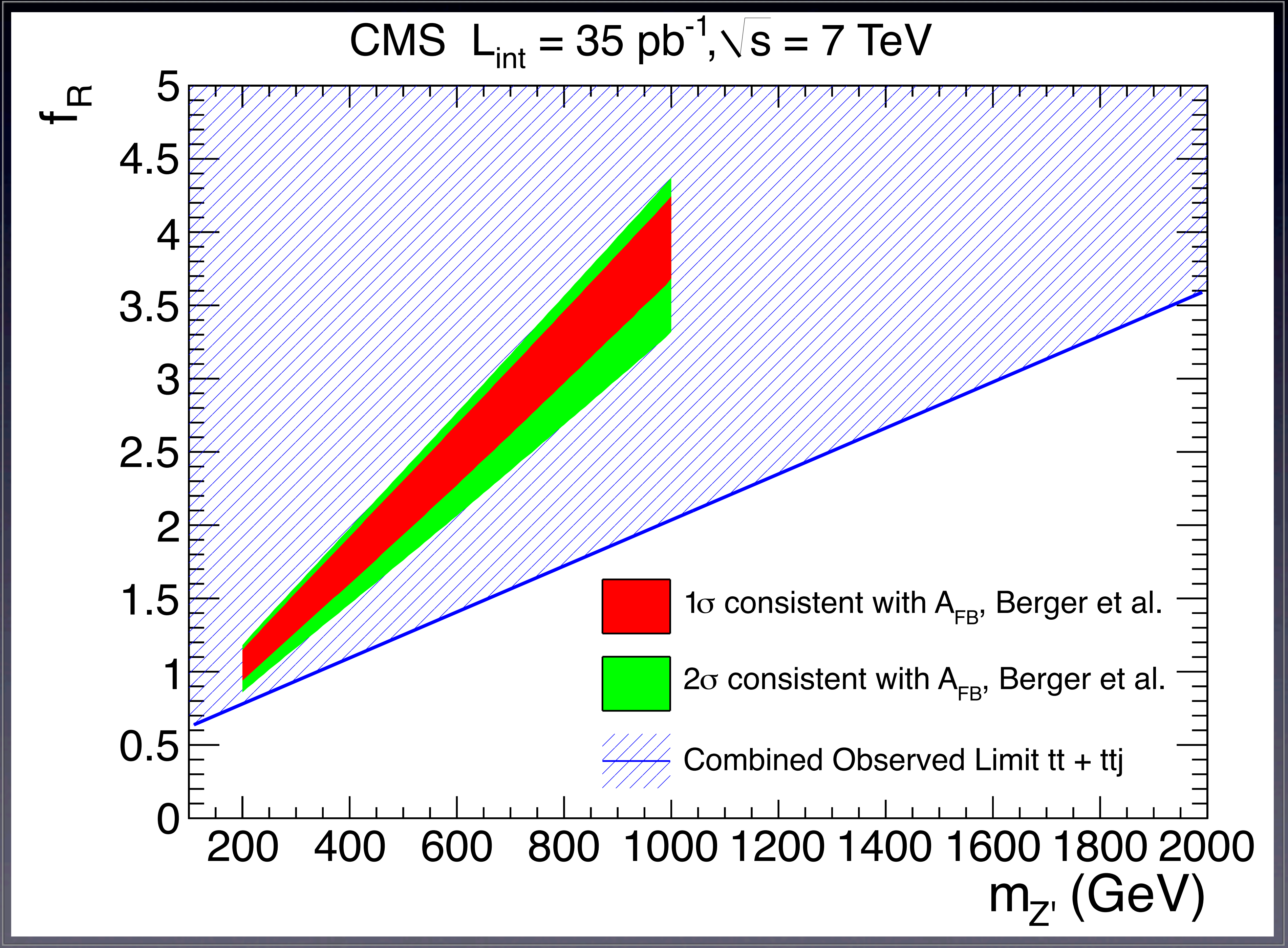
Same-sign dileptons are predicted.



FCNC Z-prime: *t*-channel

- Disfavored by CMS direct search of same-sign top pair

CMS, JHEP 1108 (2011) 005, arXiv:1106.2142



Axigluon: *s*-channel

- Purely pesudo-vector coupling

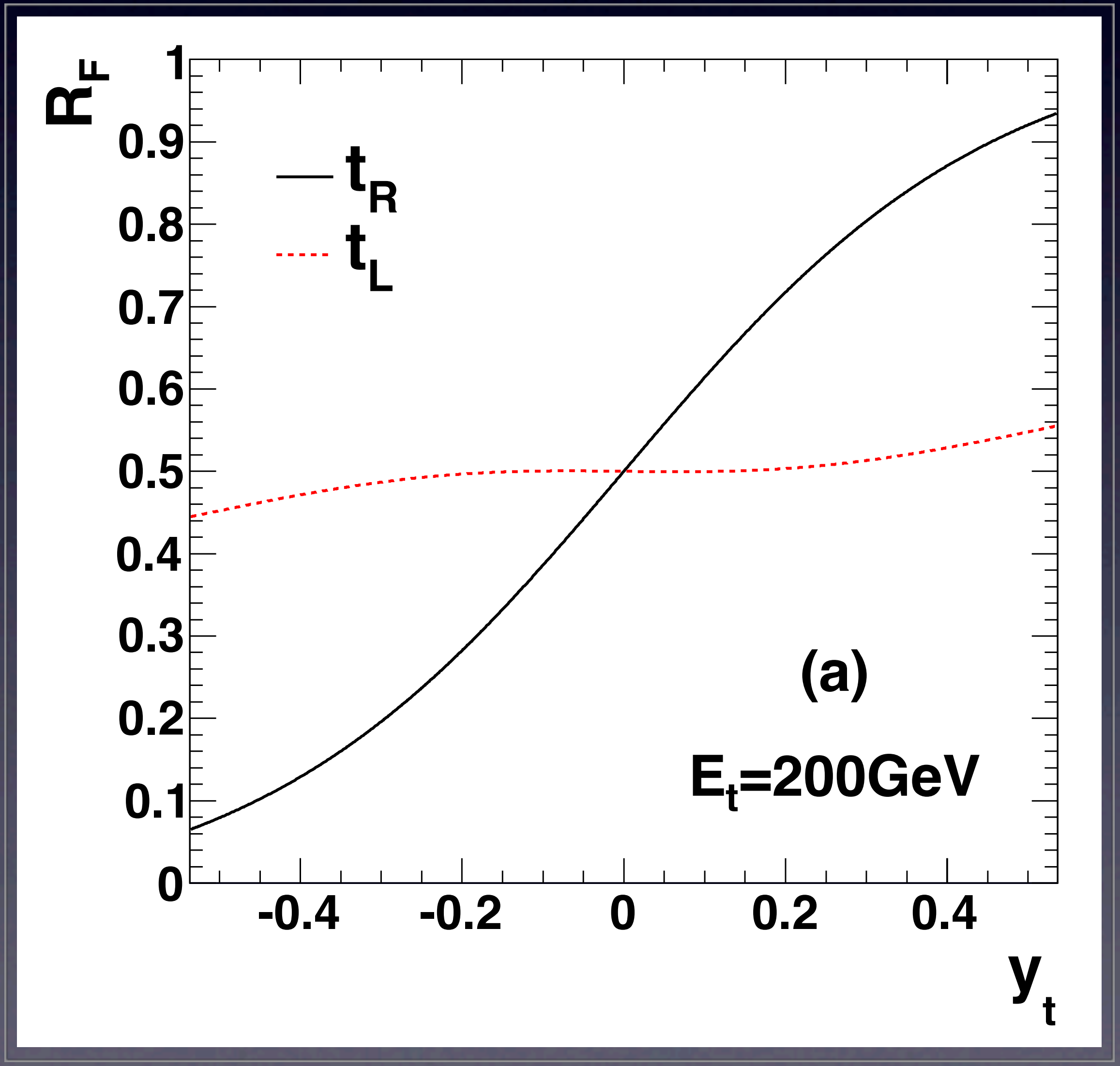
$$\mathcal{L} = g_s \left(g_l \ \bar{q}\gamma^\mu\gamma_5 q + g_h \ \bar{Q}\gamma^\mu\gamma_5 Q \right) G'_\mu$$

$$\rho_{t_L} = \rho_{t_R} = \frac{1}{2}$$

$$A_{FB}^{t_L} = A_{FB}^{t_R} = A_{FB}^{t}$$

$$A_{FB}^{\ell} \approx \rho_{t_L} A_{FB}^{t_L} \times \left(2\mathcal{R}_C^{t_L} - 1\right) + \rho_{t_R} A_{FB}^{t_R} \times \left(2\mathcal{R}_C^{t_R} - 1\right)$$

$$A_{FB}^{\ell} \lesssim \frac{1}{2} A_{FB}^{t}$$



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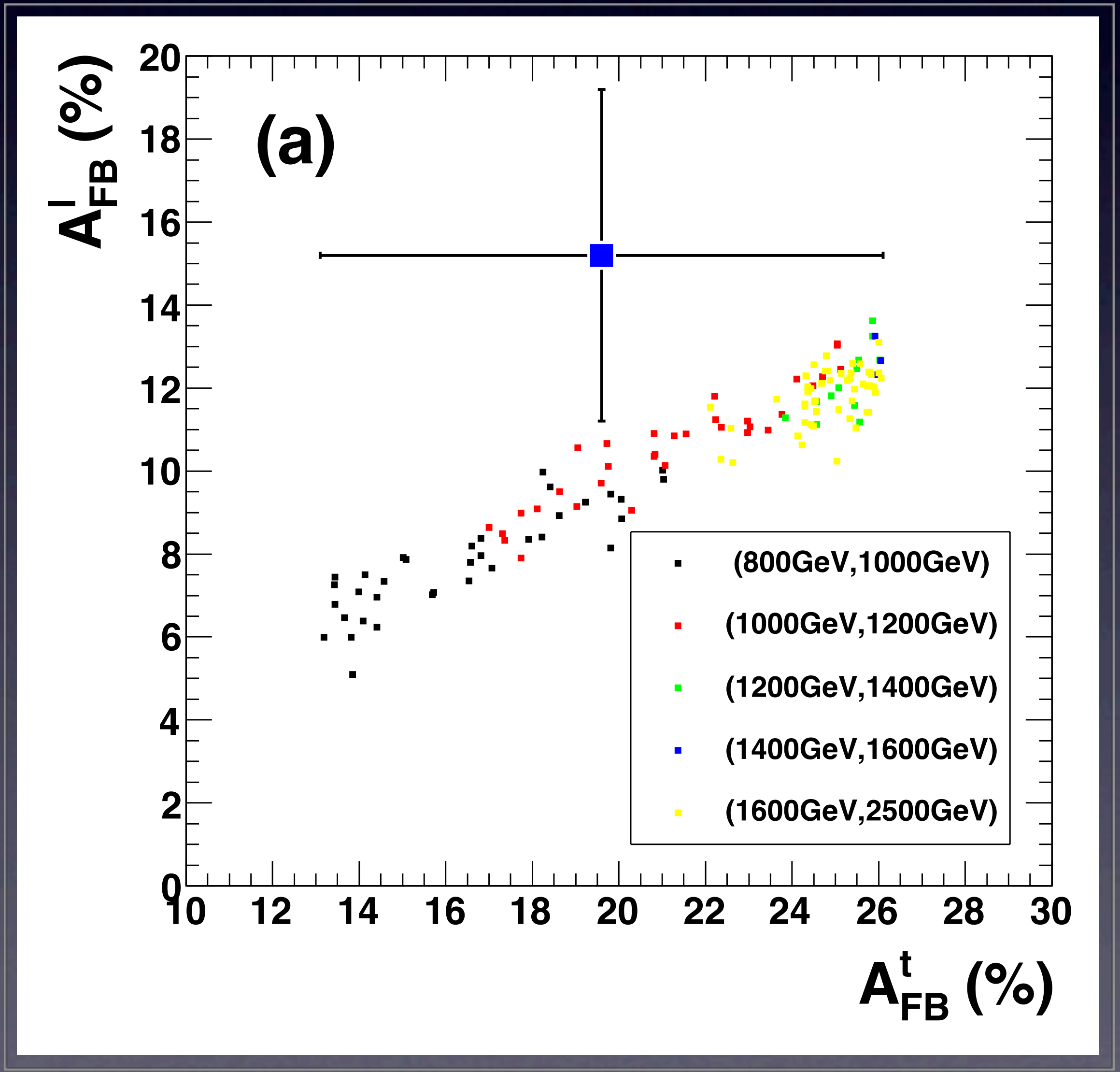


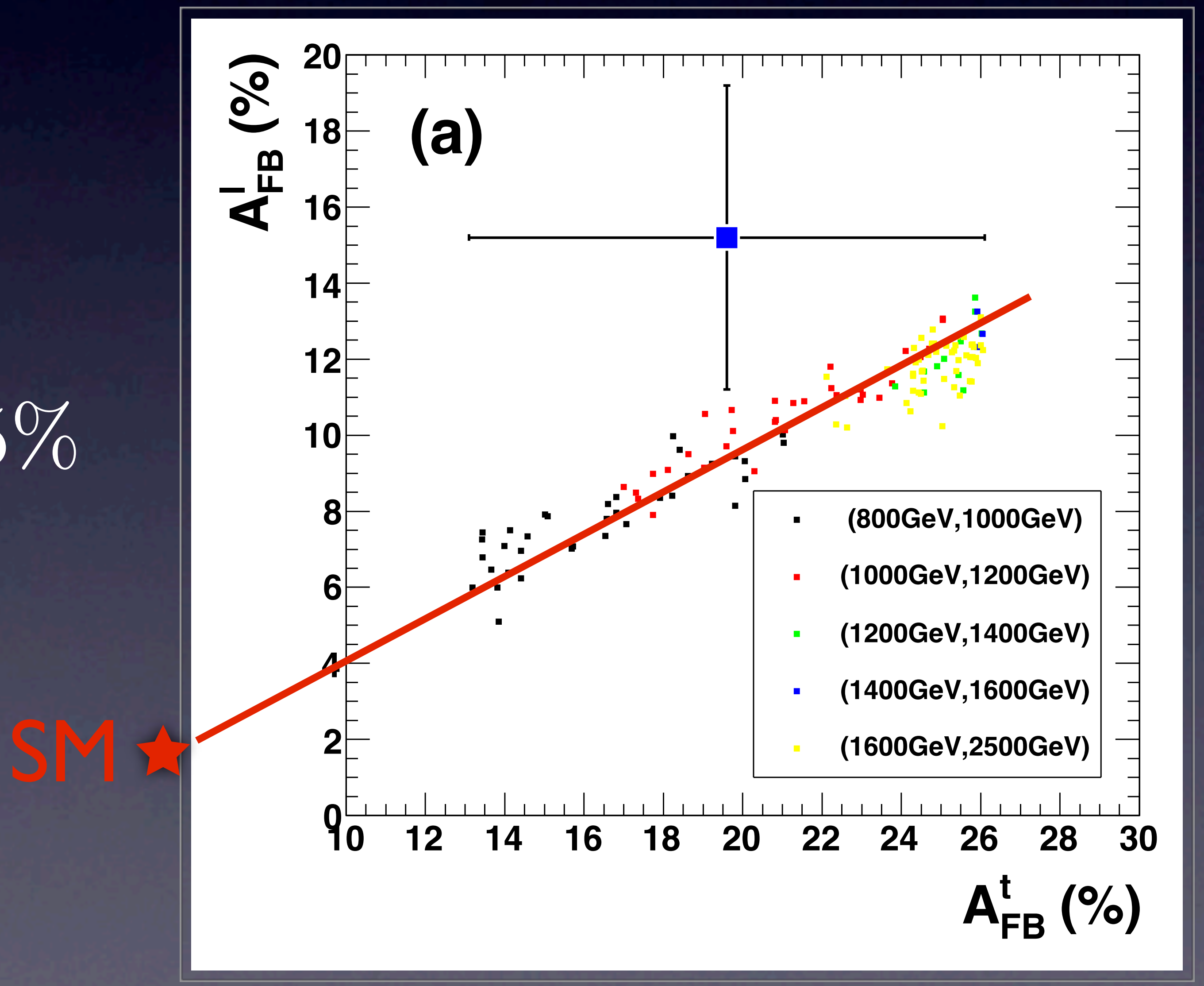
Axigluon: *s*-channel

- Purely pesudo-vector coupling

$$\mathcal{L} = g_s \left(g_l \; \bar{q}\gamma^\mu\gamma_5 q + g_h \; \bar{Q}\gamma^\mu\gamma_5 Q \right) G'_\mu$$

- Best-fit

$$A^\ell_{FB} \simeq 0.47 \times A^t_{FB} + 0.25\%$$



FC W-prime: *t*-channel

- Purely right-handed flavor changing interaction

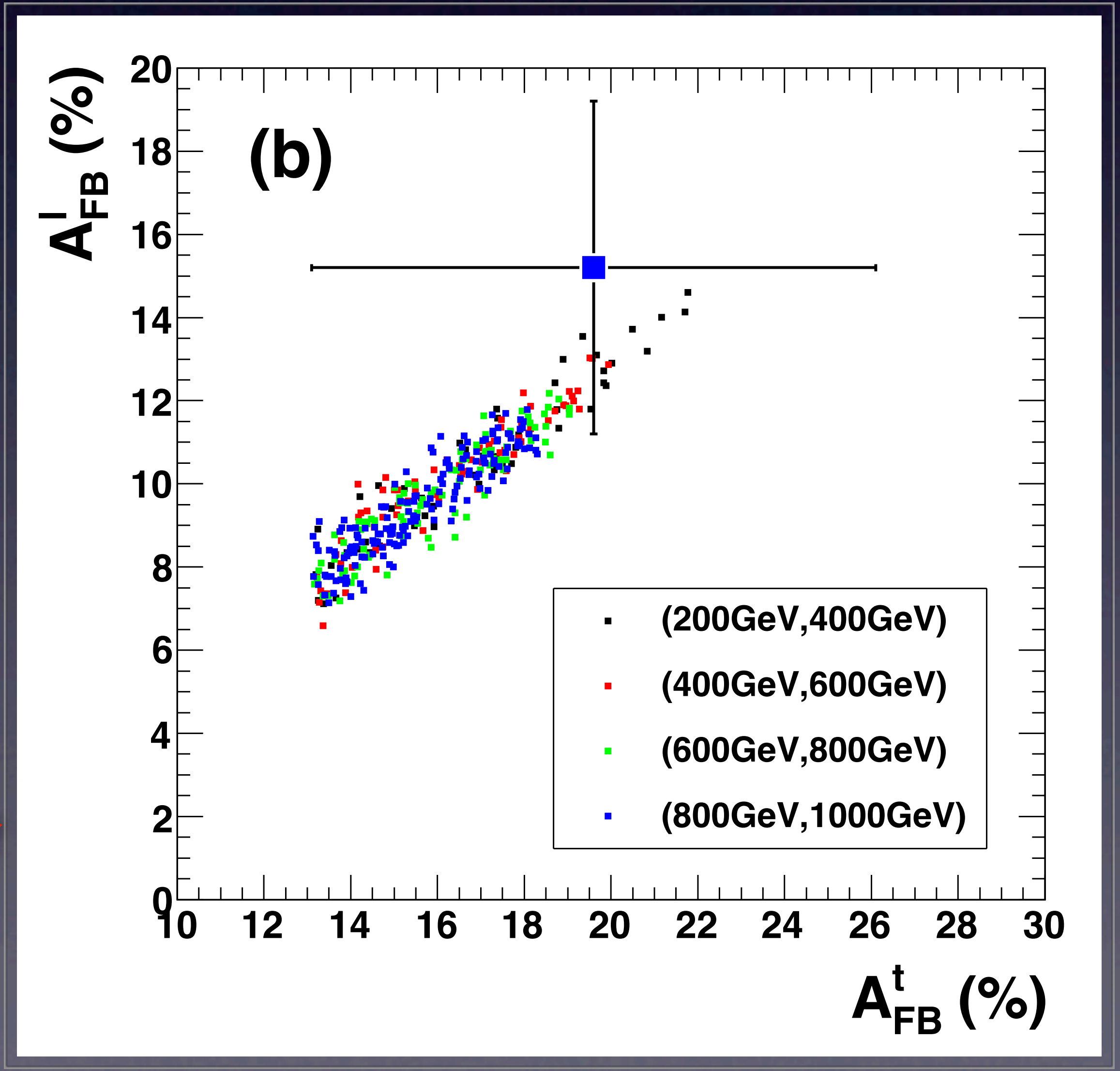
$$\mathcal{L} = g_2 g_R \bar{d}\gamma^\mu P_R t W'_\mu + h.c.$$

$$\rho_{t_R} > \rho_{t_L}$$

- Best-fit

$$A^\ell_{FB} \simeq 0.75 \times A^t_{FB} - 2.1\%$$

SM ★



Conclusion

- A^t_{FB} and A^ℓ_{FB} is connected by the top-quark and charged lepton spin correlation.

$$A^\ell_{FB} \approx \rho_{t_L} A^{t_L}_{FB} \times \left(2\mathcal{R}^{t_L}_C - 1\right) + \rho_{t_R} A^{t_R}_{FB} \times \left(2\mathcal{R}^{t_R}_C - 1\right)$$

★ $\rho_{t_L} \ll \rho_{t_R}$

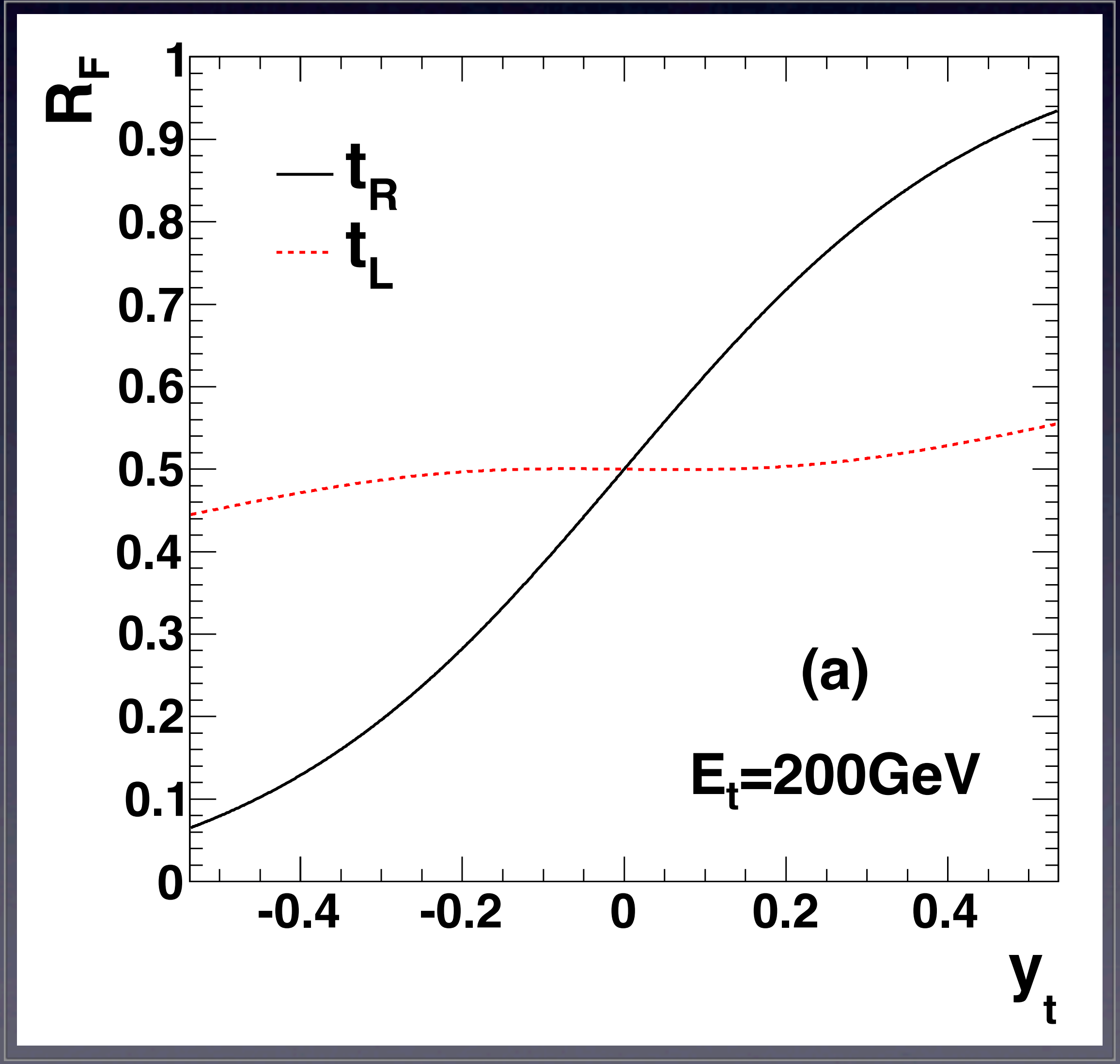
$$A^\ell_{FB} \lesssim \frac{1}{2} A^t_{FB}$$

★ $\rho_{t_L} = \rho_{t_R}$

$$A^\ell_{FB} \lesssim \frac{1}{2} A^t_{FB}$$

★ $\rho_{t_L} \gg \rho_{t_R}$

$$A^\ell_{FB} \gtrsim \frac{1}{2} A^t_{FB}$$



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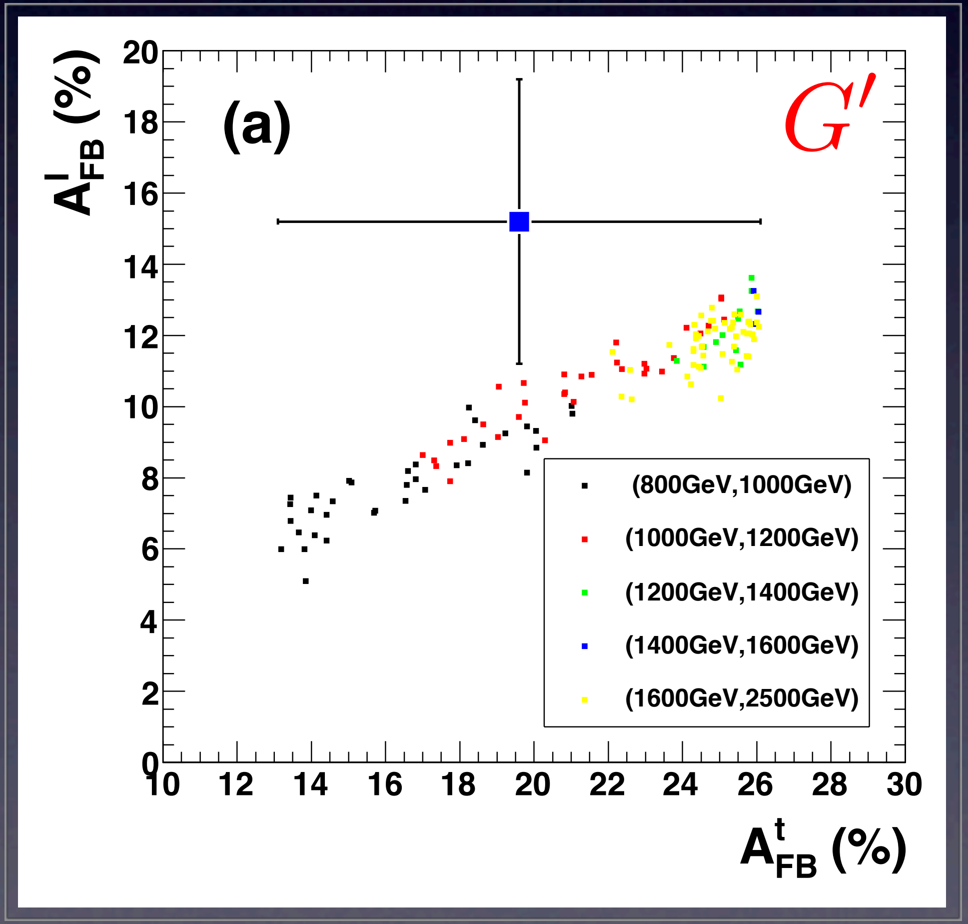

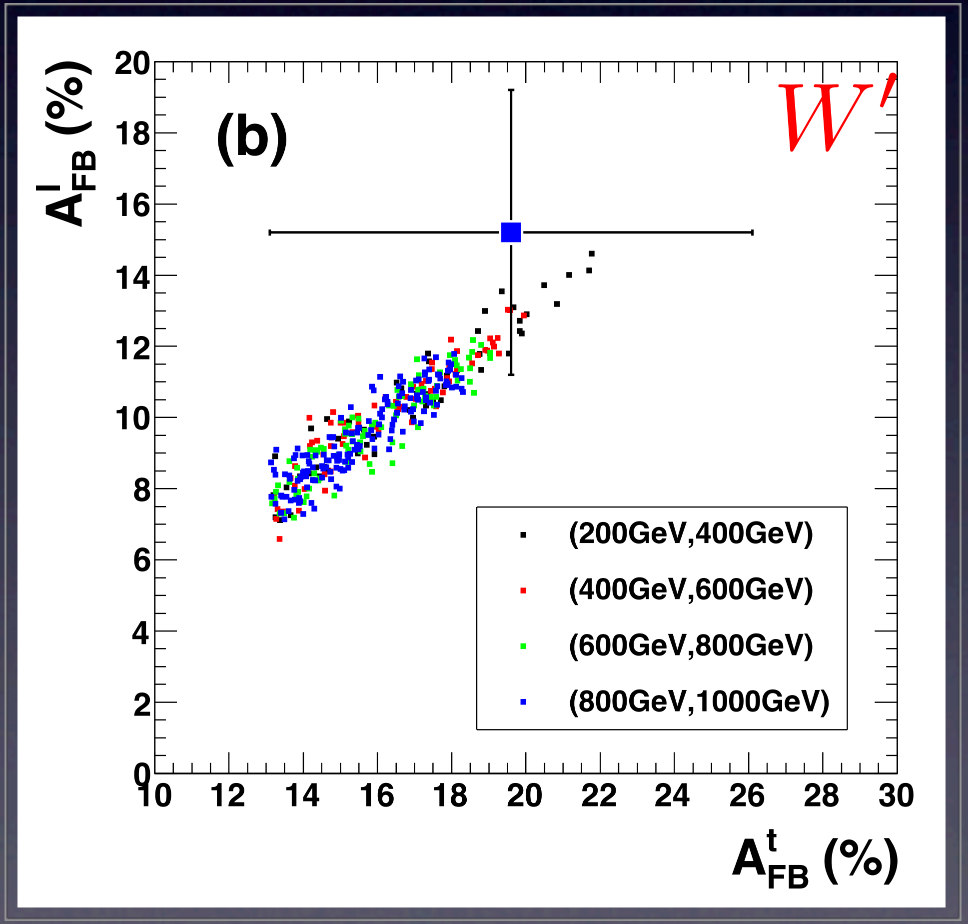

$$A^\ell_{FB} \simeq 0.47 \times A^t_{FB} + 0.25\%$$

$$A^\ell_{FB} \simeq 0.75 \times A^t_{FB} - 2.1\%$$

Thank you !

A_{FB}^{t} versus A_{FB}^{ℓ}