The 3rd generation quarks in warped models : *LHC predictions from LEP/Tevatron anomalies*

G. Moreau
Laboratoire de Physique Théorique, Orsay, France

From

A.Djouadi, G.M., F.Richard, R.Singh **PRD 2010**

+ work in progress..

GDR-Terascale

IPN/Lyon - 20/04/2011

PLAN

I) Introduction: a warped model

II) A^t_{FB} and tt cross section @ Tevatron

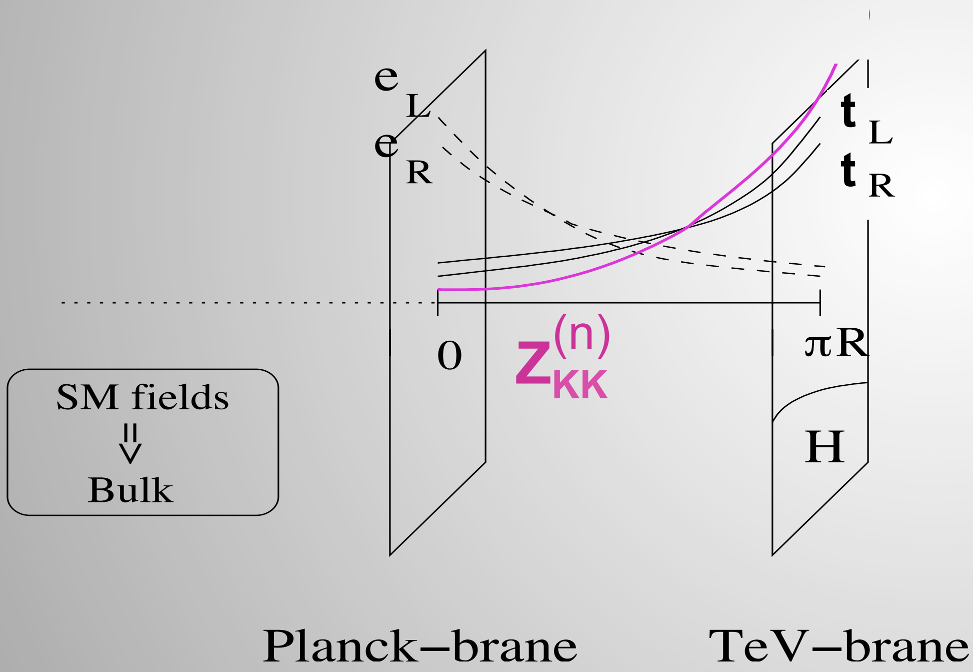
III) A^b_{FB} and EW precision tests @ LEP

IV) Constraints and predictions @ LHC

V) Conclusions

I) Introduction: a warped model

The Randall-Sundrum (RS) scenario with bulk fields:



- **RS addresses the gauge** ***hierarchy*** **:**

$$M_{grav} \approx TeV \approx Q_{EW}$$

Randall, Sundrum (1999)

- **RS generates the mass** ***hierarchies*** **:**

$$m_e << m_t$$

Gherghetta, Pomarol (2000)

...

→ **New Physics effects in the heavy fermion sector !**

+ *other attractive features of the RS scenario:*

- WIMP candidates for the dark matter of universe:
  a LKP stable due to a possible KK-parity *(like in UED)*
- Unification of gauge couplings *(as in ADD)* at high-energies
- Fermion mixing angles and flavor structure *(as in ADD)* $\neq$ ***in SUSY***
- *Extra-Dimensions* =
  necessary ingredients for higher-energy string theories

AdS / CFT correspondance (98') :

WARPED H-DIM. SCENARIOS / STRONGLY COUPLED MODELS

5D holographic version	RS with bulk fields	gauge-Higgs unification	Higgsless models
4D dual interpretation	composite Higgs boson	composite Higgs pseudo-Goldstone boson of a global symmetry *(as for little Higgs with T parity)*	technicolor models

The EW precision constraints in the warped models:

Bulk gauge bosons/fermions mix with their KK excitations

=> tree-level contributions to EW observables

Ways out to respect the constraints from EW precision data for M_{KK}~TeV :

~> Gauge custodial symmetry in the bulk

Agashe, Delgado, May, Sundrum (2003)

$$\begin{array}{ccc} O(4) & & SU(2)_L \times SU(2)_R \\ \Downarrow & \approx & \Downarrow \\ O(3) & & SU(2)_V \times P_{LR} \end{array}$$

~> Brane-localized kinetic terms for fermions/gauge fields

Carena et al. (2002) *Aguila et al. (2003)*

~> Modification of the AdS metric in the vicinity of the IR brane

Cabrer, Gersdorff, Quiros (2010)

We consider the quark representations under $SU(2)_L \times SU(2)_R \times U(1)_X$:

$$\begin{pmatrix} t_{1L} & b'_L & q'_{-4/3L} \\ b_{1L} & q''_{-4/3L} & q'_{-7/3L} \end{pmatrix}_{-5/6} \quad \begin{pmatrix} t_{2L} \\ b_{2L} \end{pmatrix}_{1/6} \quad (b_R \; q'_{-4/3R})_{-5/6} \quad (t_R \; b'_R)_{1/6}$$

custodians

$SU(2)_R \rightarrow U(1)_R$

$U(1)_R \times U(1)_X \rightarrow U(1)_Y$

$W_R^3 \quad B_X \rightarrow B_Y \quad (+ Z'^{KK})$

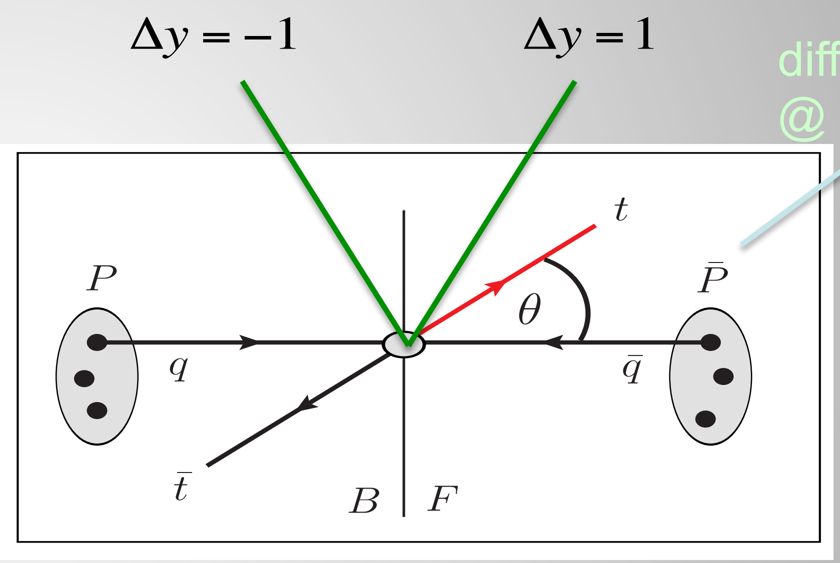
Z' charges (I_{3R} isospin) and coupling ($g_{Z'} \sim 3$)

=> **Zbb** couplings allowing to address A^b_{FB}

II) A^t_{FB} and tt cross section @ Tevatron

A^t_{FB} at Tevatron

« What is the Forward-Backward asymmetry for the top quark ? »



difficult @ LHC

≠ 0 with Parity-violating couplings

$$A^t_{\rm FB} = \frac{\sigma^F - \sigma^B}{\sigma^F + \sigma^B} = \frac{\sigma[\cos\theta^*_t : 0 \to 1] - \sigma[\cos\theta^*_t : -1 \to 0]}{\sigma[\cos\theta^*_t : 0 \to 1] + \sigma[\cos\theta^*_t : -1 \to 0]} = \frac{\sigma[y_t > 0] - \sigma[y_t < 0]}{\sigma[y_t > 0] + \sigma[y_t < 0]}$$

(tt rest frame)

Rapidity : $y_t = \frac{1}{2}\ln[(E + p_z)/(E - p_z)] = \Delta y/2$

« How is A^t_{FB} measured at Tevatron in lepton+jet channels ? »

$$\Delta y = y_t - y_{\bar{t}} \qquad y_t = (y_t - y_{\bar{t}})/2$$

$$\Delta y = q(y_l - y_h) = q\Delta y_{lh}$$

$t \rightarrow W^+ b$, $W^+ \rightarrow l^+ \nu$

$t \rightarrow W^+ b$, $W^+ \rightarrow j\,j$

↙ in the laboratory frame

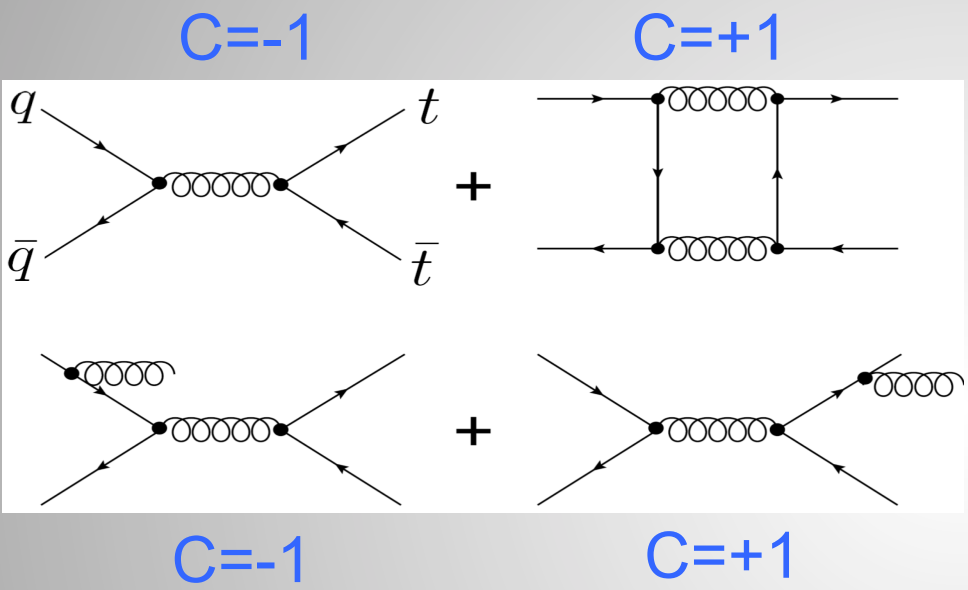
$$A^t_{\mathrm{FB}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} = \frac{N(q\Delta y_{lh} > 0) - N(q\Delta y_{lh} < 0)}{N(q\Delta y_{lh} > 0) + N(q\Delta y_{lh} < 0)}$$

Other asymmetries…

$$A^{p\bar{p}}_{\mathrm{FB}} = \frac{\sigma[y^{p\bar{p}}_t > 0] - \sigma[y^{p\bar{p}}_t < 0]}{\sigma[y^{p\bar{p}}_t > 0] + \sigma[y^{p\bar{p}}_t < 0]}$$

$$A^t_{\mathrm{C}} = \frac{\sigma_t[y_t > 0] - \sigma_{\bar{t}}[y_t > 0]}{\sigma_t[y_t > 0] + \sigma_{\bar{t}}[y_t > 0]} \qquad A^t_{\mathrm{C}} = A^t_{\mathrm{FB}} => CP$$

Standard Model (QCD) contribution to A^t_{FB}



$$A_{\rm FB}^{SM} = \frac{\sigma^F_{SM-NLO} - \sigma^B_{SM-NLO}}{\sigma^F_{SM-NLO} + \sigma^B_{SM-NLO}}$$

(vanishing at LO)

MCFM for SM *(m_t=172.5GeV, PDF=CTEQ)* @ NLO : **A^t_{FB} = 0.058** +/- 0.009

Ahrens et al. (2010) obtain *(m_t=173.1GeV, PDF=MSTW)* :

@ NLO : **A^t_{FB} = 0.067 $^{+0.006}_{-0.004}$** @ NNLO-approx : **A^t_{FB} = 0.064 $^{+0.009}_{-0.007}$** ($0.2 < \mu_f / TeV < 0.8$)

=> A^t_{FB} [M_{tt}>450GeV] anomaly probably not fully explained by QCD errors ~0.01

Measurements of A^t_{FB} at Tevatron

now 5.1fb^{-1}: see F.Badaud's talk

07-2010 D0 in the lepton+jets channel with **(0.9fb^{-1} then) 4.3fb^{-1}**
(ttbar frame, not unfolded = no subtracting bckgrd & effic. + no ttbar level) :
A^t_{FB} = 0.08 +/- 0.04 +/- 0.01 (**+1.7 sigma** from SM prediction)

03-2009 CDF in the lepton+jets channel with **(1.9fb^{-1} then) 3.1fb^{-1}**
(lab frame, unfolded) :
A^t_{FB} = 0.193 +/- 0.065 +/- 0.024 (**+2.1 sigma** from SM prediction)

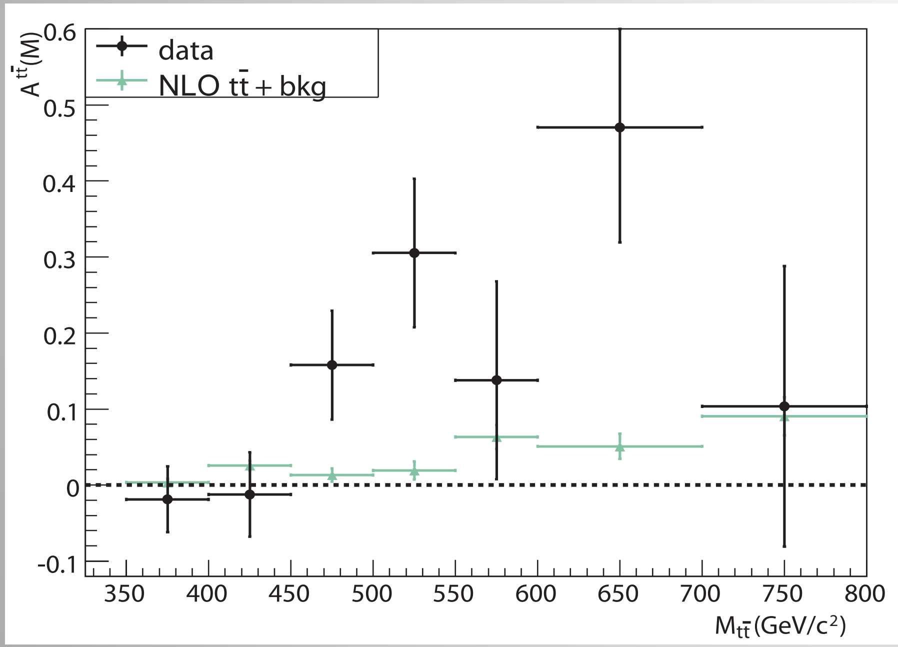
01-2011 CDF in the dilepton channel with **5.1fb^{-1}**
(lab frame, unfolded) :
A^t_{FB} = 0.42 +/- 0.15 +/- 0.05 (+2.3 sigma from SM prediction)
(large error => +1.7 sigma from lept.+jets channel)
(lab frame, not unfolded) :
A^t_{FB} (M_{tt}<450GeV)= 0.104 +/- 0.066 (+1.6 sigma from SM prediction)
A^t_{FB} (M_{tt}>450GeV)= 0.212 +/- 0.096 (**+2.6 sigma** from SM prediction)

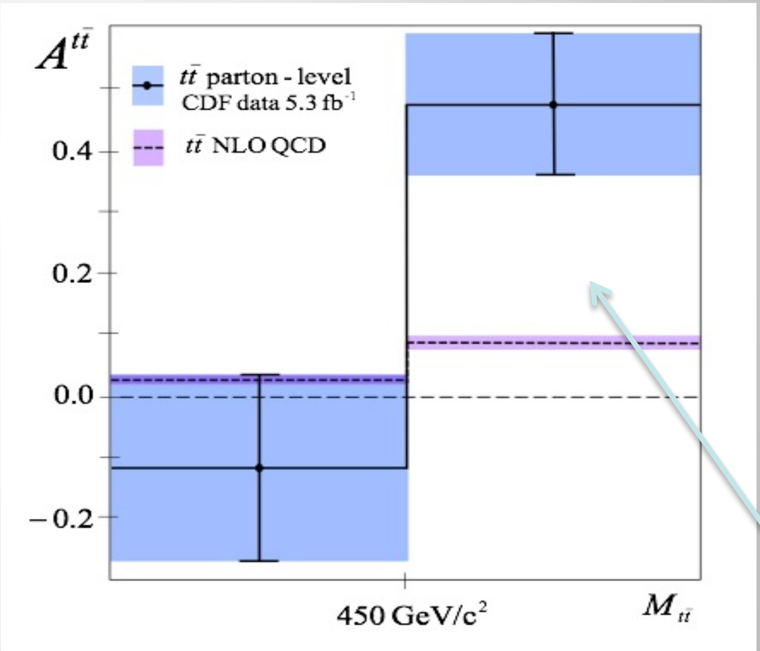
the data we use cause: most recent, unfolded and the only ones on rapidity dependence

01-2011 CDF in the lepton+jets channel with **5.3fb^{-1}**

(ttbar frame, unfolded) :

A^{t}_{FB} = 0.158 +/- 0.075 (**+1.3 sigma** from SM prediction)

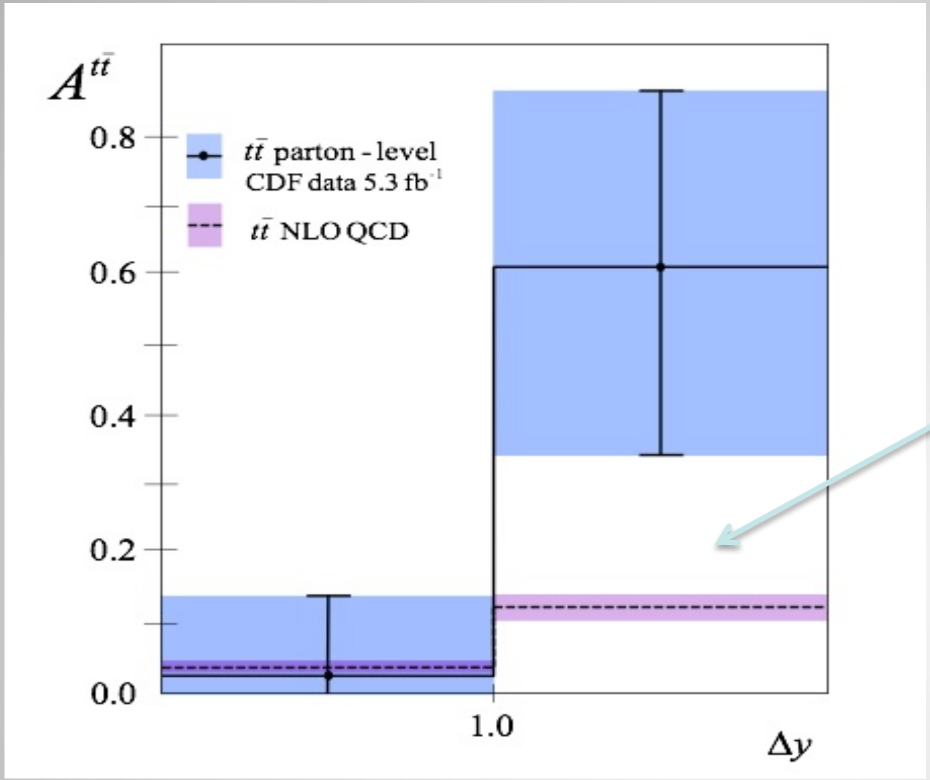




(ttbar frame)

unfolding

+3.4 standard deviations from SM



+1.9 standard deviation from SM

(ttbar frame, unfolded)

$$A_{\rm FB}^{|\Delta y|<1} = \frac{N(1 > \Delta y > 0) - N(-1 < \Delta y < 0)}{N(1 > \Delta y > 0) + N(-1 < \Delta y < 0)}, \quad A_{\rm FB}^{|\Delta y|>1} = \frac{N(\Delta y > 1) - N(\Delta y < -1)}{N(\Delta y > 1) + N(\Delta y < -1)}$$

$$|\Delta y| < 3$$

A^t_{FB} in the studied warped model

+ interferences with SM

(neglect EW gauge contrib. at a first level)

A^t_{FB} non-vanishing (Parity violation)

- $g_s\, Q(c\_t_L) \neq g_s\, Q(c\_t_R)$
- $g_s\, Q(c\_q_L) \neq g_s\, Q(c\_q_R)$

5D mass : c k

A^t_{FB} significant

→ *slightly closer to TeV-brane :* $c\_u_L\,,\, c\_d_L \lesssim 0.5$

→ $M_{KK} \sim 1.5$ - 2 TeV

EW tests not so far treated in this setup

A^t_{FB} in the studied warped model

+ interferences with SM

(neglect EW gauge contrib. at a first level)

A^t_{FB} non-vanishing (Parity violation)

- $g_s\, Q(c\_t_L) \neq g_s\, Q(c\_t_R)$
- $g_s\, Q(c\_q_L) \neq g_s\, Q(c\_q_R)$

5D mass : c k

A^t_{FB} significant

→ *slightly closer to TeV-brane :* c_u_L, $c\_d_L \lesssim 0.5$

→ M_{KK} ~ 1.5 - 2 TeV

EW tests not so far treated in this setup

We will show that EW fits are OK for :

c_u/d_L~0.43, c_u/d_R~0.8, c_c/s_L~0.6, c_c_R~0.6, c_s_R~0.51, c_t/b_L~0.5, c_b_R~0.55, c_t_R~-0.5

The way to compute it…

$$A_{\rm FB}^{t} = \frac{(\sigma_{SM}^{F} + \sigma_{RS}^{F} + \sigma_{inter.}^{F}) - (\sigma_{SM}^{B} + \sigma_{RS}^{B} + \sigma_{inter.}^{B})}{(\sigma_{SM}^{F} + \sigma_{RS}^{F} + \sigma_{inter.}^{F}) + (\sigma_{SM}^{B} + \sigma_{RS}^{B} + \sigma_{inter.}^{B})}$$

$$\Leftrightarrow \quad A_{\rm FB}^{t} = A_{\rm FB}^{RS} \times R + A_{\rm FB}^{SM} \times (1 - R)$$

Cao et al. (2010)

with

$$\begin{cases} A_{\rm FB}^{RS} = \dfrac{(\sigma_{RS-LO}^{F} + \sigma_{inter.-LO}^{F}) - (\sigma_{RS-LO}^{B} + \sigma_{inter.-LO}^{B})}{(\sigma_{RS-LO}^{F} + \sigma_{inter.-LO}^{F}) + (\sigma_{RS-LO}^{B} + \sigma_{inter.-LO}^{B})} \\ R = \dfrac{\sigma_{RS-LO}^{\rm total} + \sigma_{inter.-LO}^{\rm total}}{\sigma_{SM-LO}^{\rm total} + \sigma_{RS-LO}^{\rm total} + \sigma_{inter.-LO}^{\rm total}} \end{cases}$$

<u>ex:</u>

$$\sigma_{RS-LO}^{F} = \sigma_{RS-LO}[\cos\theta_t^* : 0 \to 1] =$$

$$\sum_{ij} \int_{\tau_{min}}^{\tau_{max}} d\tau \Big[\int_0^1 d\cos\theta_t^* \left(\frac{{\rm d}\hat{\sigma}_{RS-LO}}{{\rm d}\cos\theta_t^*}(\tau s) \right)_{ij} \Big] \Big\{ \int_\tau^1 \frac{dx}{x} f_i(x, \mu_f) f_j(\frac{\tau}{x}, \mu_f) \Big\}$$

$$\tau_{min/max} = \hat{s}_{min/max}/s$$

MSTW-2008-NLO

It is instructive to write down the asymmetry at a partonic level (neglecting 2nd/3rd generations and gluons in initial state)…

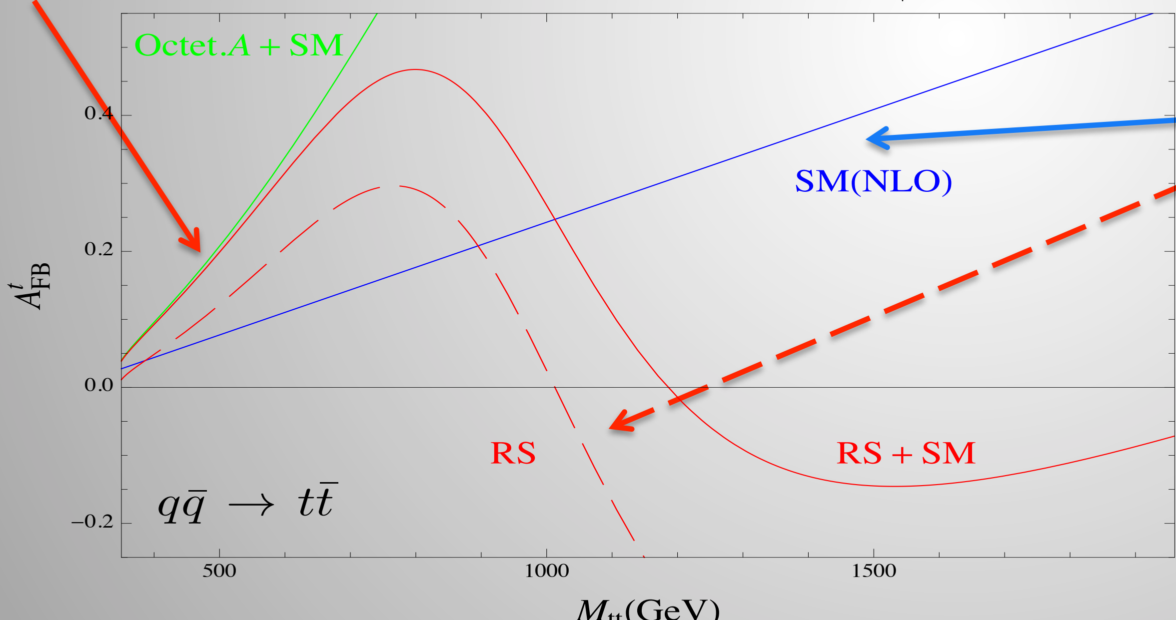
$$\hat{A}_{\rm FB}^{LO}(\hat{s}) = a_q a_t \, \frac{4\pi\alpha_s^2(\mu_r)}{9} \, \frac{\beta_t^2 \; |\mathcal{D}|^2 \left[(\hat{s}-M_{KK}^2) + 2 v_q v_t \;\hat{s}\right]}{\hat{\sigma}^{\rm total}_{SM-LO}(\hat{s}) + \hat{\sigma}^{\rm total}_{RS+inter.-LO}(\hat{s})}$$

$$\left[\begin{aligned} a_q &= (Q(c_{q_R}) - Q(c_{q_L}))/2, \\ a_t &= (Q(c_{t_R}) - Q(c_{t_L}))/2, \\ v_q &= (Q(c_{q_R}) + Q(c_{q_L}))/2, \\ v_t &= (Q(c_{t_R}) + Q(c_{t_L}))/2, \end{aligned}\right.$$

$\not{P}$

$$\hat{A}_{\rm FB}^{NLO}(\hat{s}) = \frac{(\hat{\sigma}^F_{SM-NLO}(\hat{s}) + \hat{\sigma}^F_{RS+inter.-LO}(\hat{s})) - (\hat{\sigma}^B_{SM-NLO}(\hat{s}) + \hat{\sigma}^B_{RS+inter.-LO}(\hat{s}))}{\hat{\sigma}^{\rm total}_{SM-NLO}(\hat{s}) + \hat{\sigma}^{\rm total}_{RS+inter.-LO}(\hat{s})}$$

$$\simeq \hat{A}_{\rm FB}^{LO}(\hat{s}) + \hat{A}_{\rm FB}^{SM-NLO}(\hat{s})$$



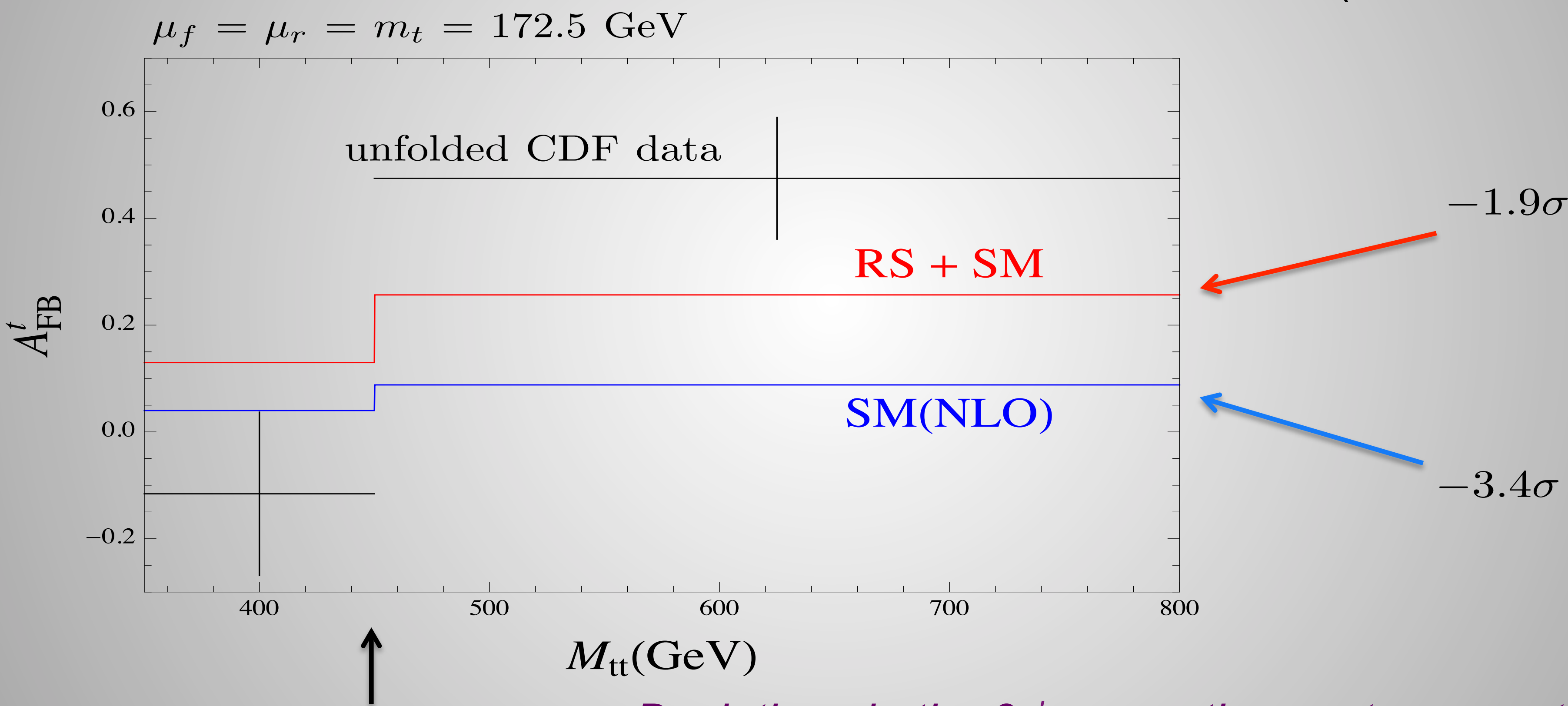
For our parameters such that:

$a_q a_t$ = -1.16 $v_q v_t$ = 0.59

⇒ Positive A^{LO}_{FB} in RS at low M_{tt} ..as wanted !

Full asymmetry after convolution with PDF…

(ttbar frame)



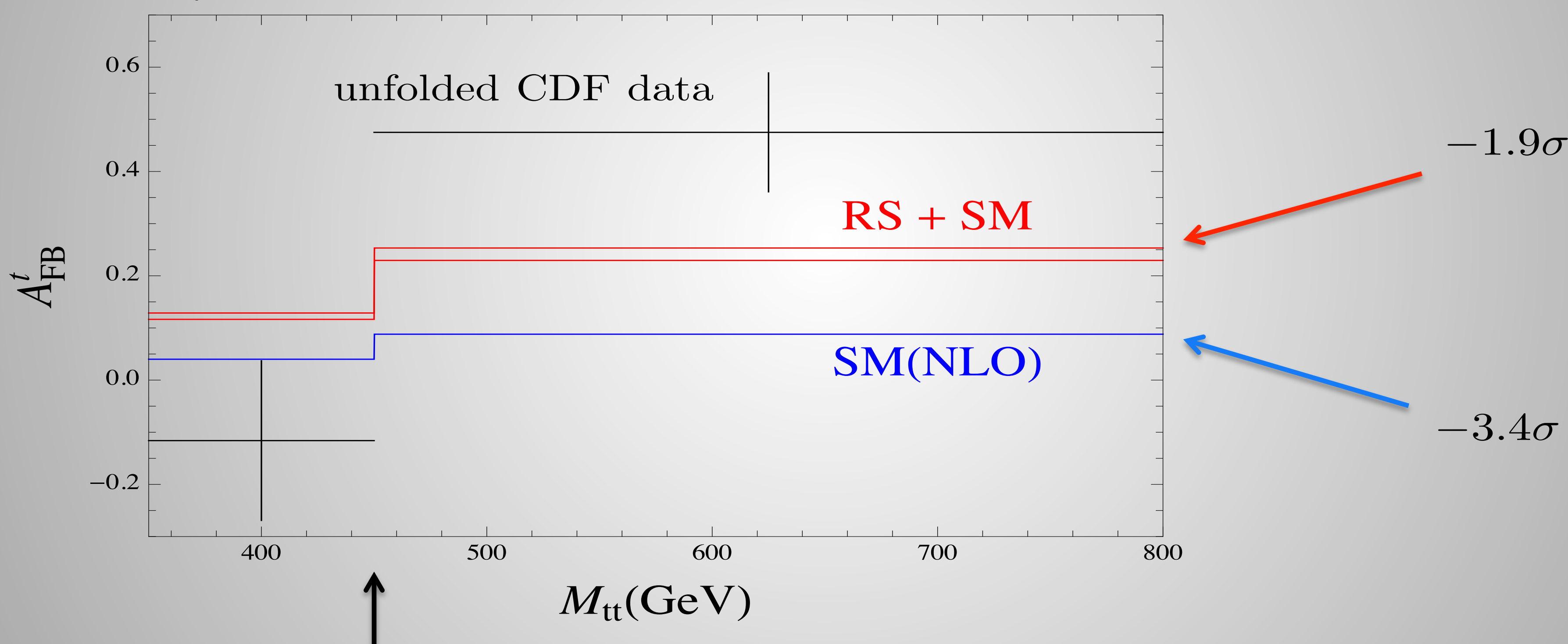
M_{tt} = 450GeV

Deviations in the 3rd generation sector expected in the warped/composite models and observed (!)

Looking at the effect of MSTW *uncertainties [@ 90%C.L.]…*

(ttbar frame)

$\mu_f = \mu_r = m_t = 172.5$ GeV

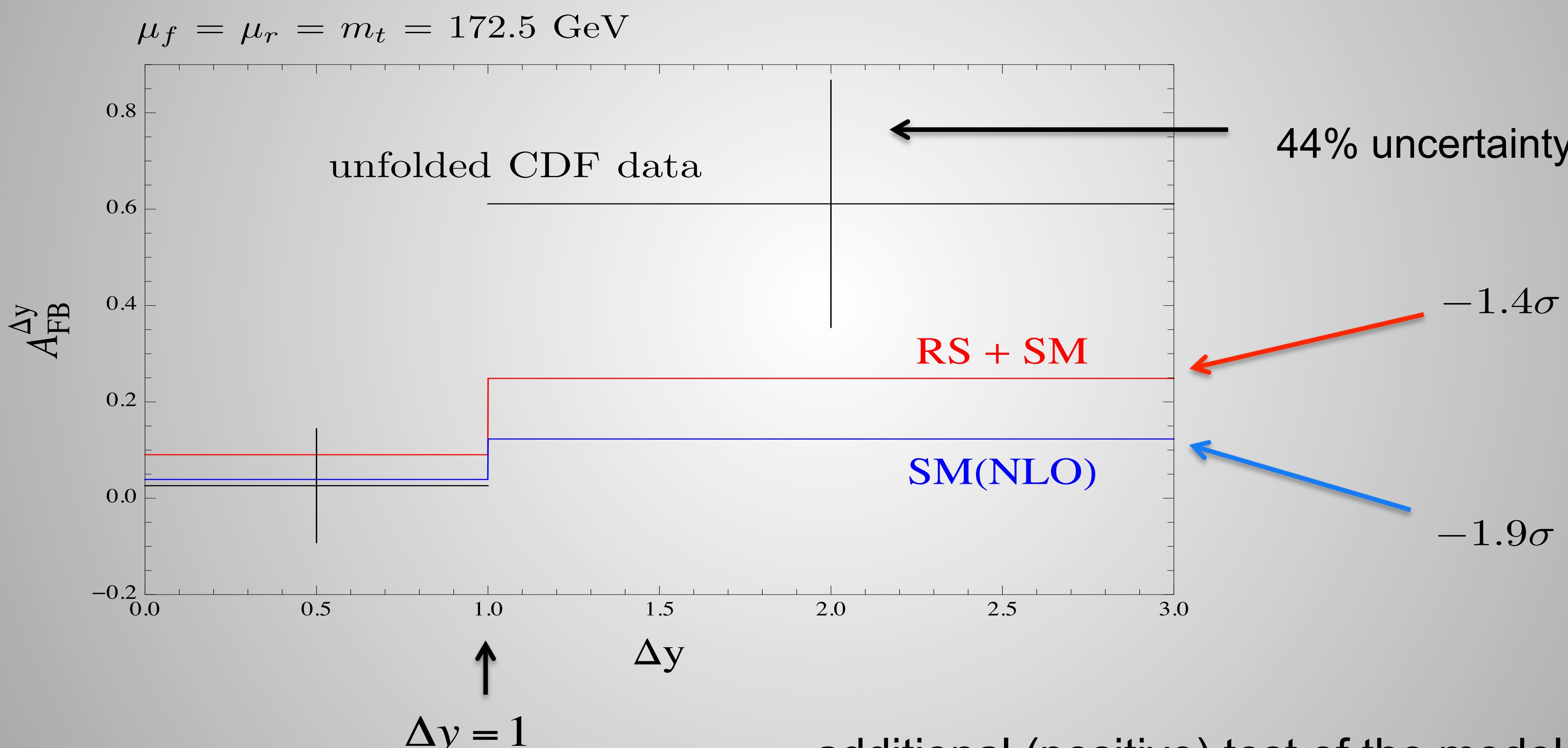


M_{tt} = 450GeV

no significant dependence as well on μ_f, μ_r and m_t

Full asymmetry as a function of rapidity…

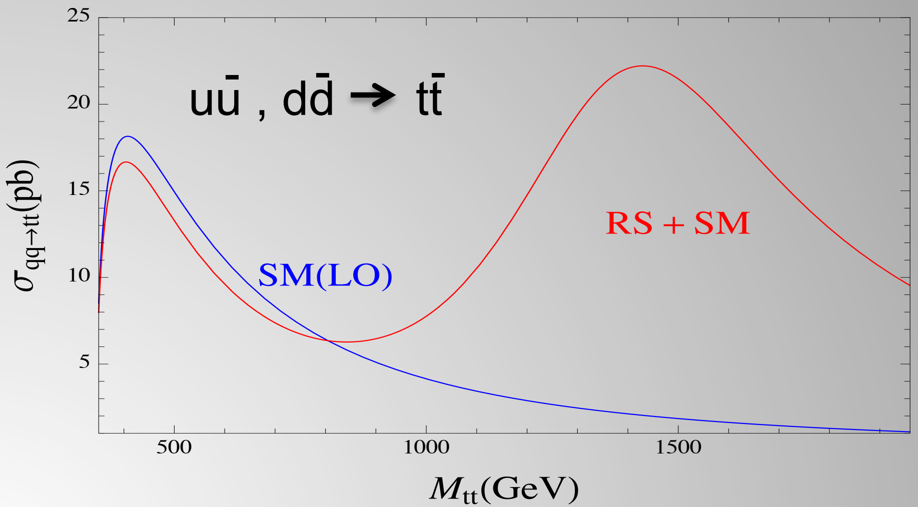
(ttbar frame)

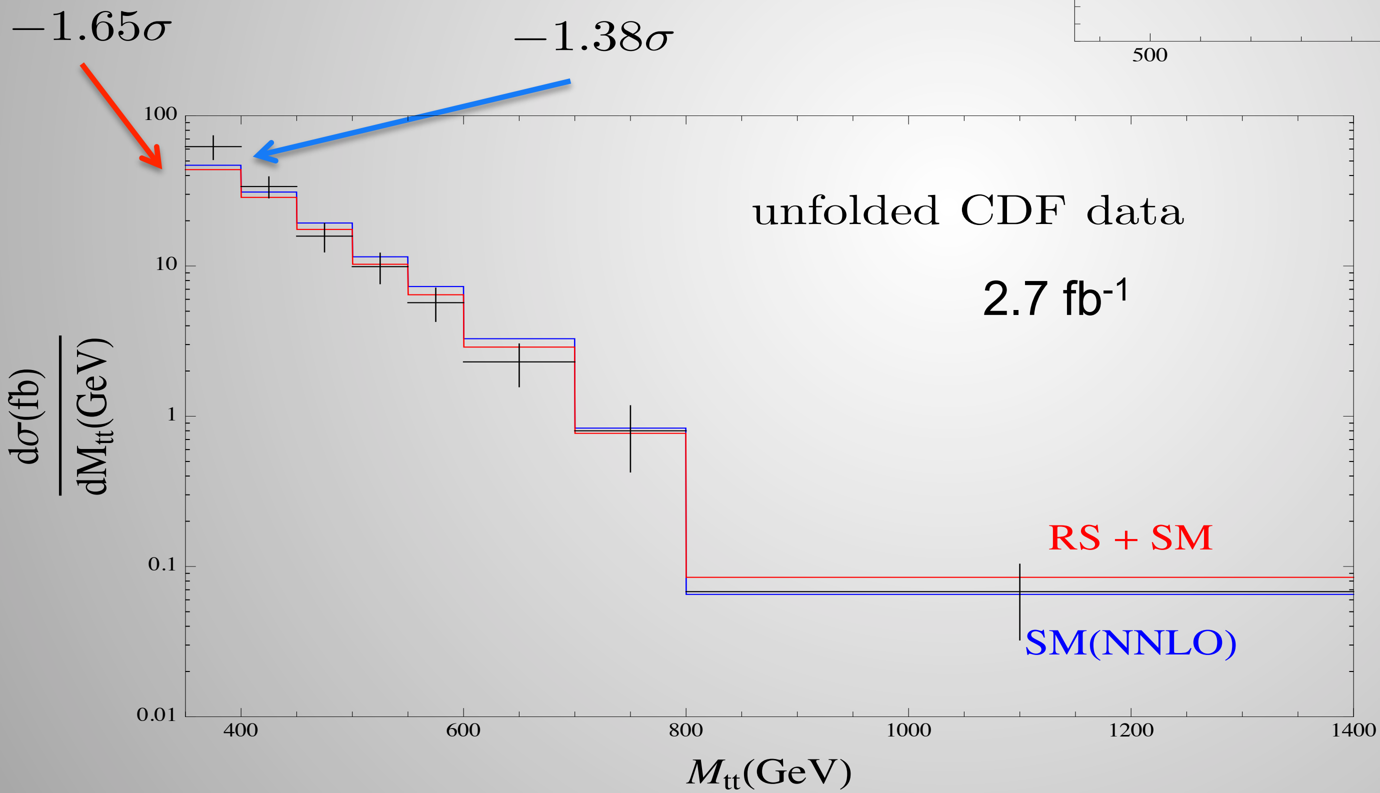


additional (positive) test of the model

One must take care of the differential tt production cross section in good agreement with the SM…

$$\frac{d\sigma_{SM-NNLO}}{dM_{t\bar{t}}}\left(1+\frac{d\sigma_{RS+inter.-LO}}{dM_{t\bar{t}}}\Big/\frac{d\sigma_{SM.-LO}}{dM_{t\bar{t}}}\right)$$





In SM :

$\chi^2/d.o.f. = 6.85/8$

In RS :

$\chi^2/d.o.f. = 5.08/8$

$m_t = 175$ GeV

$\mu_f = \mu_r = m_t$

What about the whole integrated top quark asymmetry and cross section ?

Observable	Measurement	SM [QCD-(N)NLO]	SM (dev.)	RS+SM	RS+SM (dev.)	RS+SM w.r.t. SM (%)
A^t_{FB}	0.158 ± 0.075	0.058 ± 0.009	-1.33σ	0.169	$+0.15(7)\sigma$	+192.8%
$\sigma_{t\bar{t}}$	7.50 ± 0.48 pb	7.46 pb [20]	-0.08σ	6.86 pb	-1.33σ	−8.0%
$\sigma_{t\bar{t}}$	7.50 ± 0.48 pb	7.29 pb [21]	-0.43σ	6.70 pb	-1.65σ	−8.0%
$\sigma_{t\bar{t}}$	7.50 ± 0.48 pb	7.26 pb [22]	-0.5σ	6.68 pb	-1.71σ	−8.0%

$$\mu_f = \mu_r = m_t$$

Observable	Measurement	SM [QCD-(N)NLO]	SM (dev.)	RS+SM	RS+SM (dev.)	RS+SM w.r.t. SM (%)
A^t_{FB}	0.158 ± 0.075	0.058 ± 0.009	-1.33σ	0.169	$+0.15(9)\sigma$	+193.0%
$\sigma_{t\bar{t}}$	7.50 ± 0.48 pb	7.61 pb [20]	$+0.24\sigma$	7.00 pb	-1.04σ	−8.1%
$\sigma_{t\bar{t}}$	7.50 ± 0.48 pb	7.44 pb [21]	-0.11σ	6.84 pb	-1.37σ	−8.1%
$\sigma_{t\bar{t}}$	7.50 ± 0.48 pb	7.41 pb [22]	-0.18σ	6.81 pb	-1.43σ	−8.1%

$$\mu_f = 2m_t \quad \mu_r = m_t$$

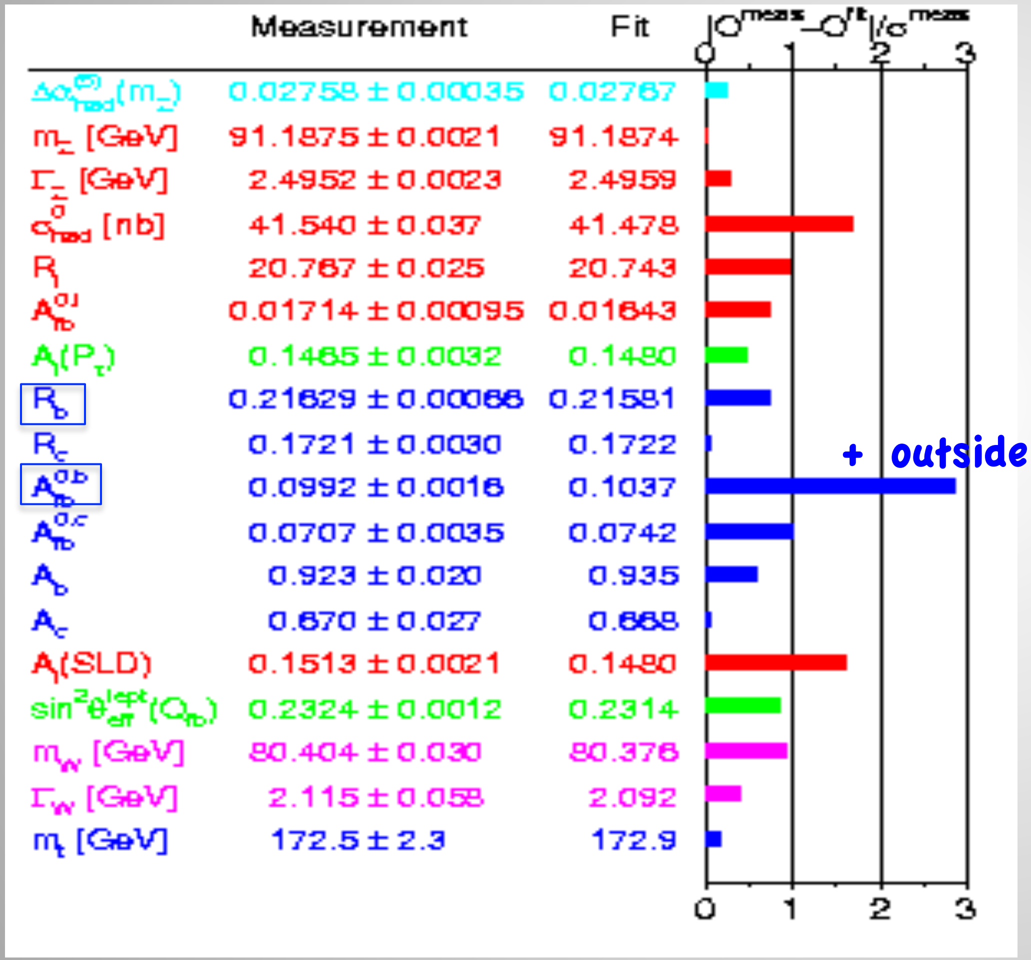
[20] *Langenfeld et al. (2009)*

[21] *Kidonakis et al. (2008)*

[22] *Cacciari et al. (2008)*

$m_t = 172.5$ GeV

III) A^b_{FB} and EW precision tests @ LEP



+ outside Z pôle !

A^b_{FB} : a NP effect in the b sector ?

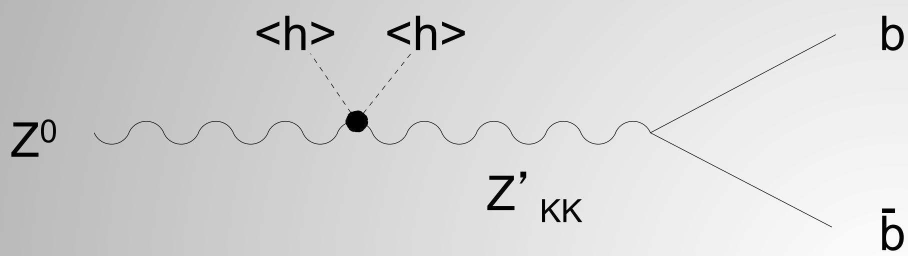
$$A^b_{FB}(p\hat{o}le) \equiv \frac{\int_0^{+1}\sigma_\theta d\cos\theta - \int_{-1}^{0}\sigma_\theta d\cos\theta}{\sigma_0(e^+e^- \to \gamma/Z \to b\bar{b})}$$

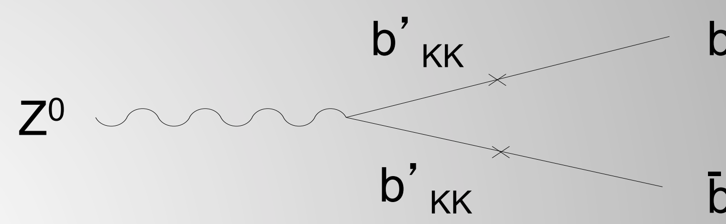
$$= \frac{3}{4}\,\frac{(Q_Z^{e_L})^2-(Q_Z^{e_R})^2}{(Q_Z^{e_L})^2+(Q_Z^{e_R})^2}\,\frac{(Q_Z^{b_L})^2-(Q_Z^{b_R})^2}{(Q_Z^{b_L})^2+(Q_Z^{b_R})^2}$$

$$R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to hadrons)}$$

$$= \frac{(Q_Z^{b_L})^2+(Q_Z^{b_R})^2}{\sum_{q\neq t}[(Q_Z^{q_L})^2+(Q_Z^{q_R})^2]}$$

Interpretation in a generic extra-dimensional model…
(difficult in SUSY)





$$\left|\delta Q_Z^{f_l}\right| \approx 1\,{}^{0}\!/_{00} \quad << \quad \left|\delta Q_Z^{b_{L/R}}\right| \approx \left|-1.5/30\%\right|$$

$$\mathrm{m}_{b'}(\mathrm{c}_{\mathrm{t_R}}) \quad << \quad \mathrm{m}_{f'}(\mathrm{c}_{\mathrm{light}})$$

$$\text{Coupling } Z_{KK} f_l \overline{f_l} \quad << \quad \text{Coupling } Z_{KK} b\bar{b}$$

$$\Downarrow$$

$$\mathrm{m}_{\mathrm{t}}(\mathrm{c}_{\mathrm{t_R}}) \uparrow \quad \Rightarrow \quad \mathrm{m}_{b'}(\mathrm{c}_{\mathrm{t_R}}) \downarrow$$

$$\Downarrow$$

'natural' conditions within the RS model

Summary of the EW observables…

Observable	SM	RS
$A^b_{FB}(m_Z)$	2.7σ	1.4σ
R_b	0.8σ	1.1σ
$A^c_{FB}(m_Z)$	0.9σ	0.7σ
R_c	0.0σ	0.5σ
$A^s_{FB}(m_Z)$	0.6σ	0.1σ
$\Gamma_{\rm had}(Z)$	1.3σ	0.8σ
$\Gamma_{\rm tot}(W)$	0.2σ	0.2σ
$\sigma_{\rm had}$	1.5σ	1.6σ
$\langle Q_{FB}\rangle$	1.1σ	0.1σ
$C_{1u}+C_{1d}$	0.2σ	0.9σ
$C_{1u}-C_{1d}$	1.1σ	0.1σ
$\chi^2/d.o.f.$	$27.5/18$	$22.0/18$

no more A^b_{FB} anomaly at the Z^0 pole

still fits well

fit improved

+ Zuu/Zdd OK from Tevatron Run I & HERA (H1,ZEUS)

IV) Constraints and predictions @ LHC

Constraint from $t\bar{t}$ cross section $\sigma_{t\bar{t}}$

$\mathcal{L} = 35 \text{ pb}^{-1}$
36 pb^{-1}

combined final states

$\sqrt{s} = 7 \text{ TeV}$

Collaboration	Measurement	SM [QCD-(N)NLO]	SM (dev.)	RS+SM (dev.)
ATLAS	180 ± 18.5 pb	164 pb [35]	-0.86σ	-0.88σ
ATLAS	180 ± 18.5 pb	163 pb [21]	-0.91σ	-0.94σ
ATLAS	180 ± 18.5 pb	155 pb [24]	-1.35σ	-1.37σ
CMS	158 ± 19 pb	164 pb [35]	$+0.31\sigma$	$+0.29\sigma$
CMS	158 ± 19 pb	163 pb [21]	$+0.26\sigma$	$+0.24\sigma$
CMS	158 ± 19 pb	155 pb [24]	-0.15σ	-0.17σ

major *gg* initial state

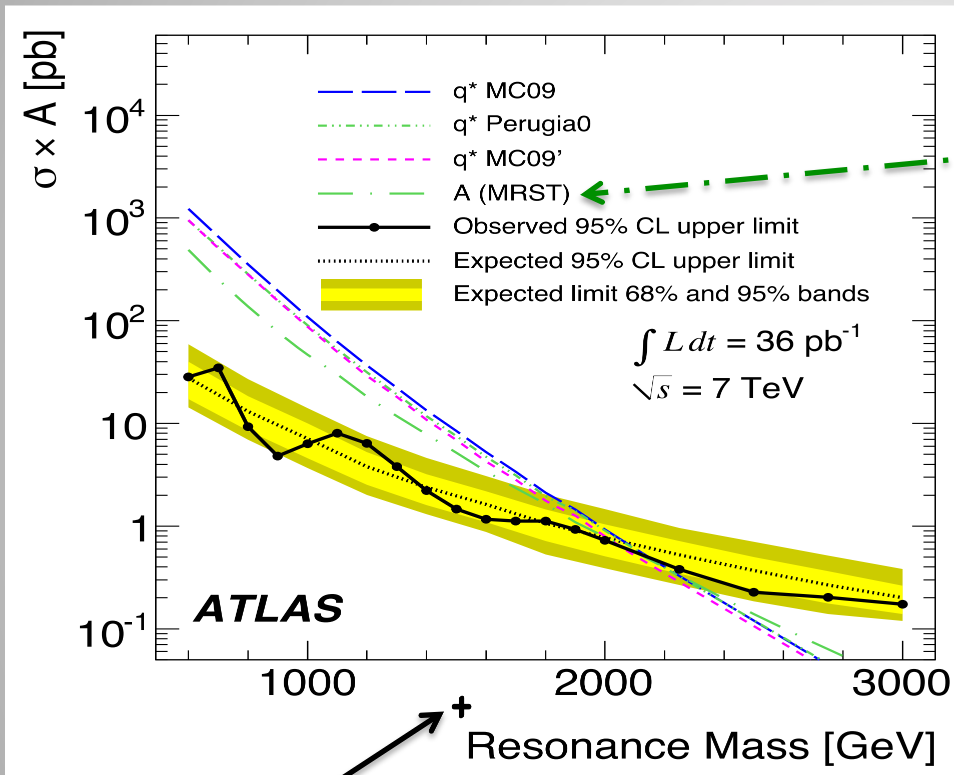
[35] HATHOR program (2011)

[21] *Kidonakis et al. (2011)*

[24] *Ahrens et al. (2009)*

$\mu_f = \mu_r = m_t = 173 \text{ GeV}$

Constraints from dijets



Axigluon - $SU(3)_L x SU(3)_R$

Frampton et al. (1987)
Bagger et al. (1987)

★ now including the width effect between 0.7 M_{KK} and 1.3 M_{KK}

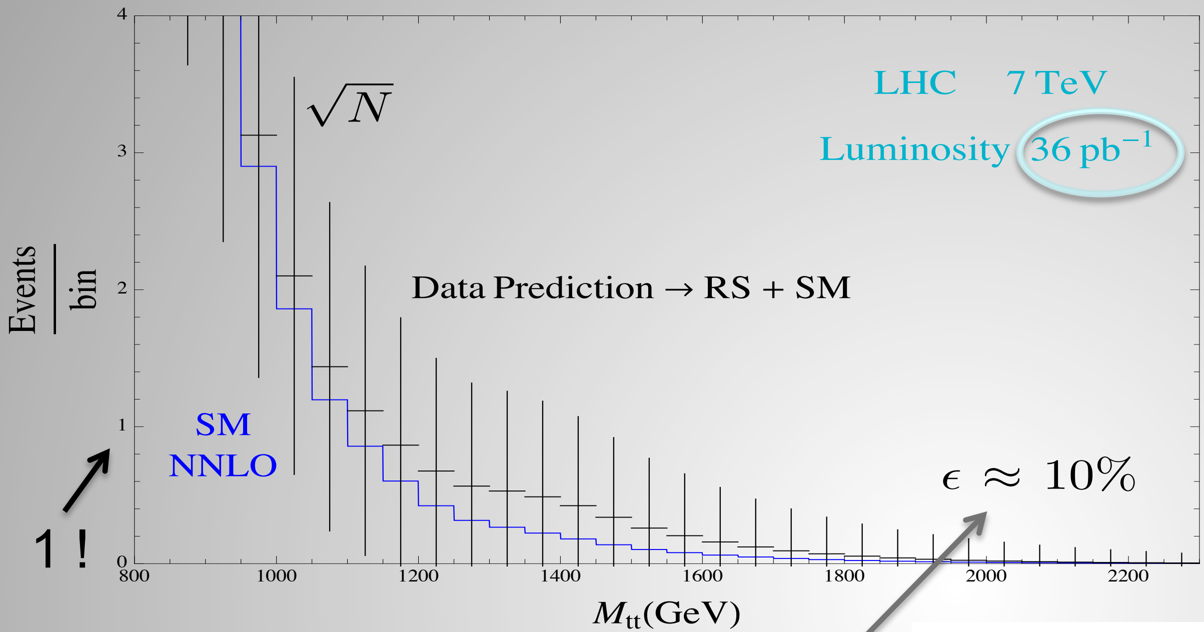
★ we have also checked the angular distribution constraints

we've computed the ratio RS/Axigluon
=> KK gluon exchange @ 0.017 pb

Coupling $g^{(1)}tt > g^{(1)}qq$

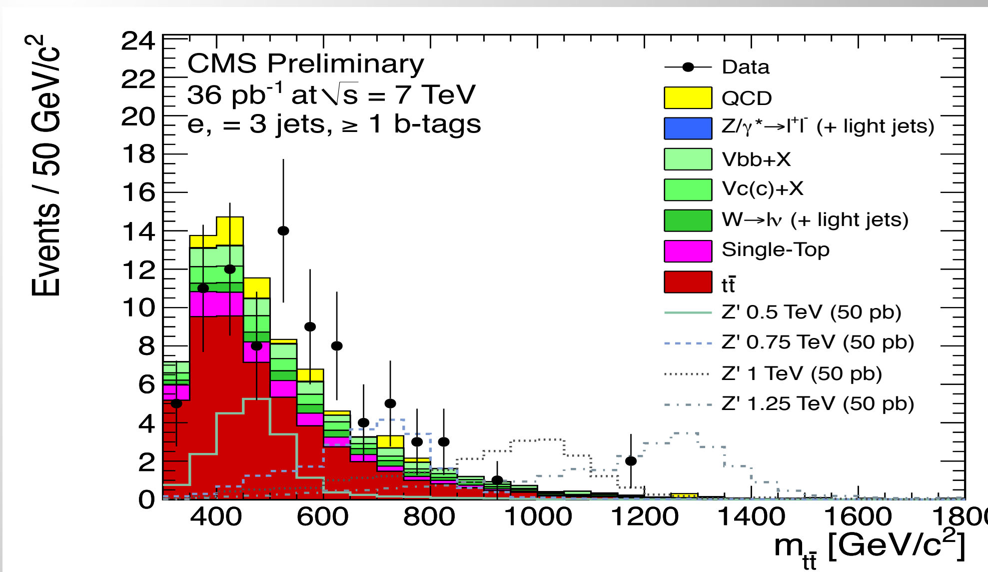
RS addresses A^t_{FB}
+ passes dijet bounds

Predictions on the M_{tt} distribution at LHC



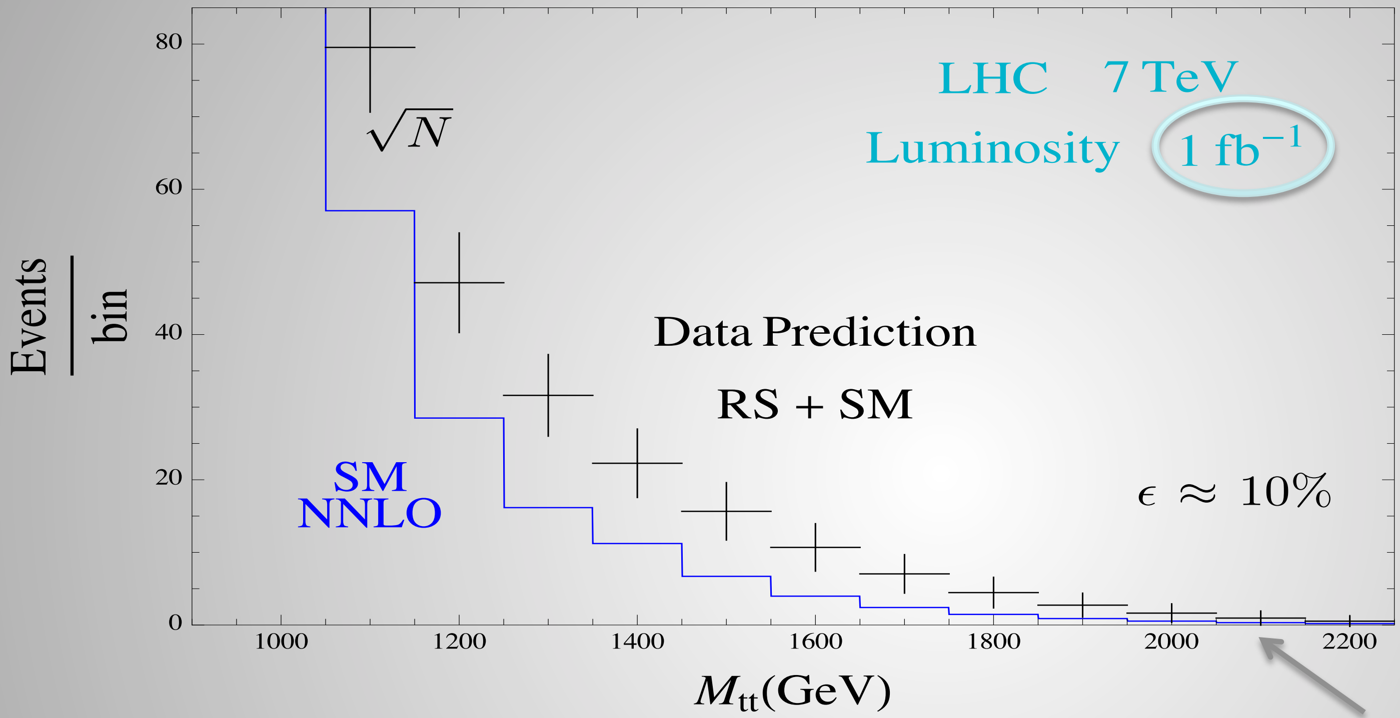
compatible

$t\bar{t}$ reconstruction efficiency taken



$$\mu_f = \mu_r = m_t = 173 \text{ GeV}$$

What does the RS model predicts at the expected luminosity of 1 fb^{-1} ?



assuming 100 GeV bin resolutions

$\Gamma_{KK}/M_{KK} \simeq 832$ GeV $/1500$ GeV $\simeq 0.55$

↳ integration of the cross section e.g. over $[1050, 1750]$ GeV

↳ $(Signal - Background)/\sqrt{Background} \simeq 5$ (with $Signal = RS + SM$)

An excess should be visible..

..for $\mu_f = \mu_r = m_t = 173$ GeV

The predicted $t\bar{t}$ excess due to KK gluon is observable but not 'spectacular'

the pair production of ~10^2GeV colored fermions [« **custodian** » b'] might be *(in particular due to the increase factor induced by : $q\bar{q} \rightarrow g^{(1)} \rightarrow b'\bar{b}'$).*

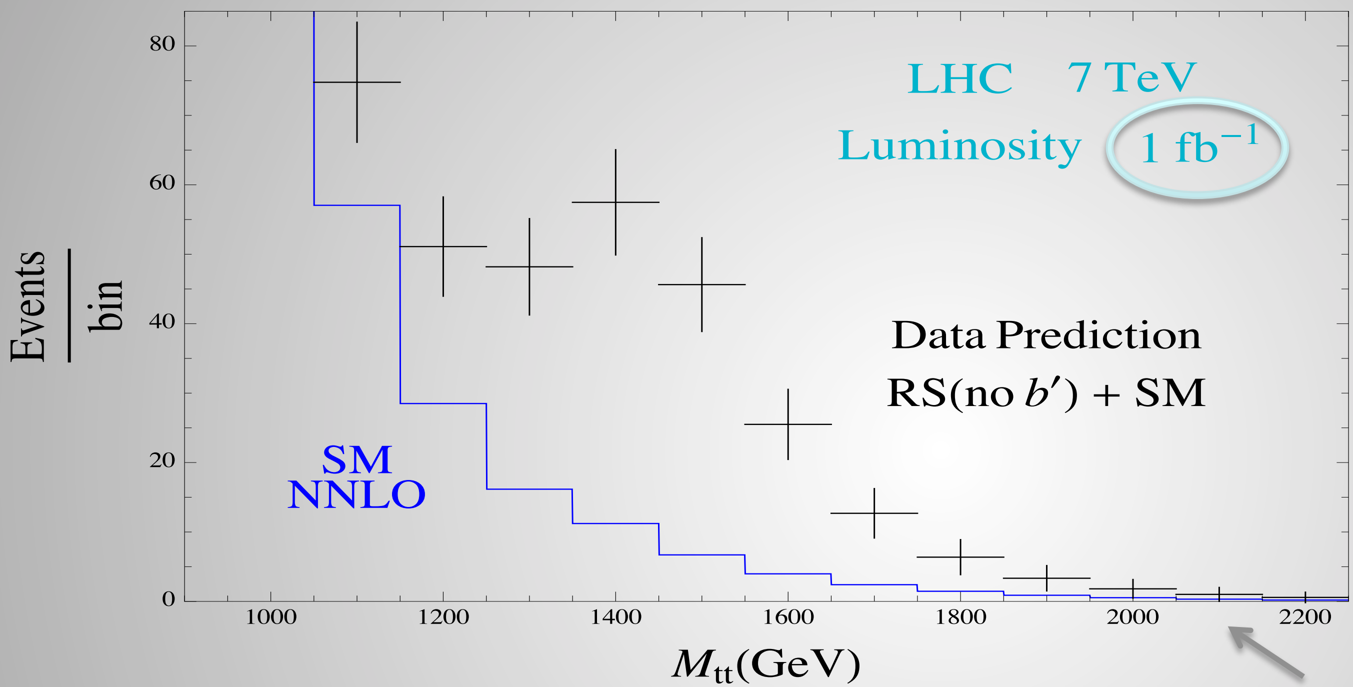
Let's assume now a slightly different scenario solving A^b_{FB}, A^t_{FB} as we showed but **without custodian** effects at present colliders :

- heavy custodians (by mixing with higher KK states, in a multiplet with larger **c** value, coupled to Planckian/bulk masses, …)

- custodial symmetry implemented *à la Mohapatra* i.e. without new fermions, e.g. with (t_R,b_R), thanks to more structured Higgs sector

- without custodial symmetry: EWPT protected by brane-kinetic terms or modified geometrical background and A^b_{FB} curred by Z^{KK}.

Without b' like fermion, the RS model predicts a nice $g^{(1)}$ resonant peak…

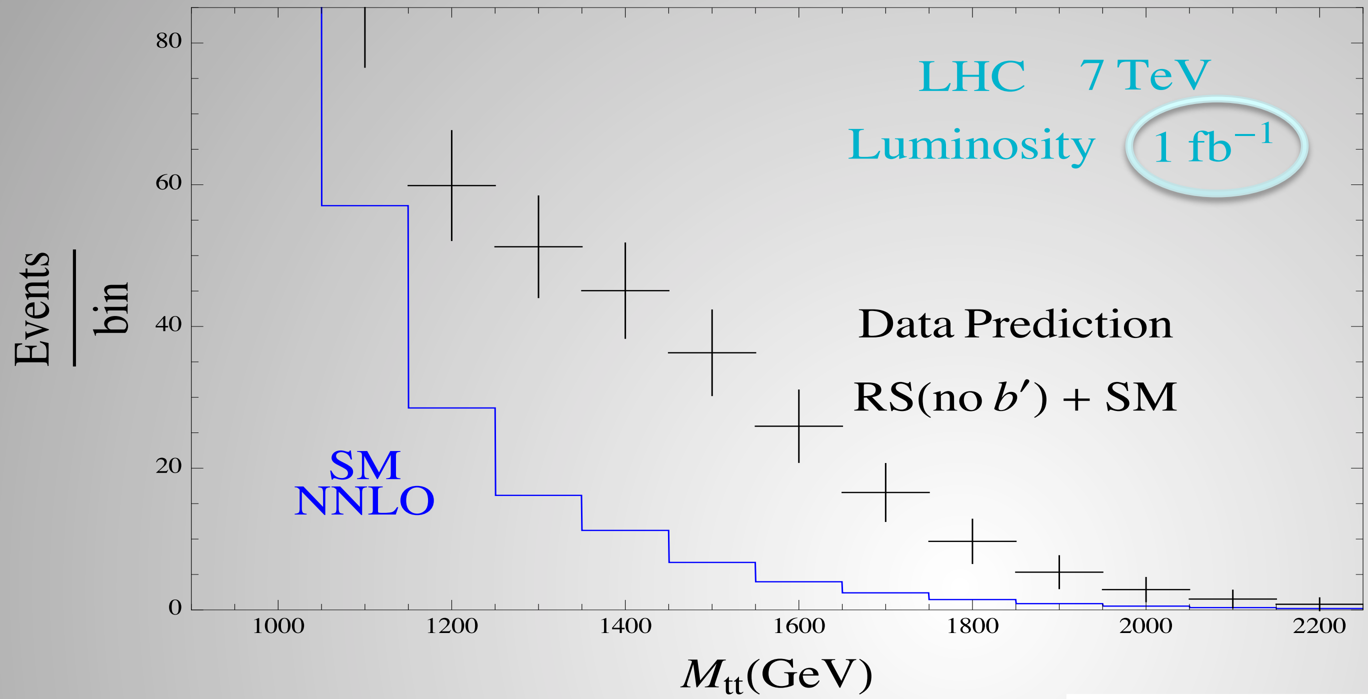


assuming 100 GeV bin resolutions

Smaller total KK gluon width cause no more channel $g^{(1)} \longrightarrow b'\bar{b}'$:

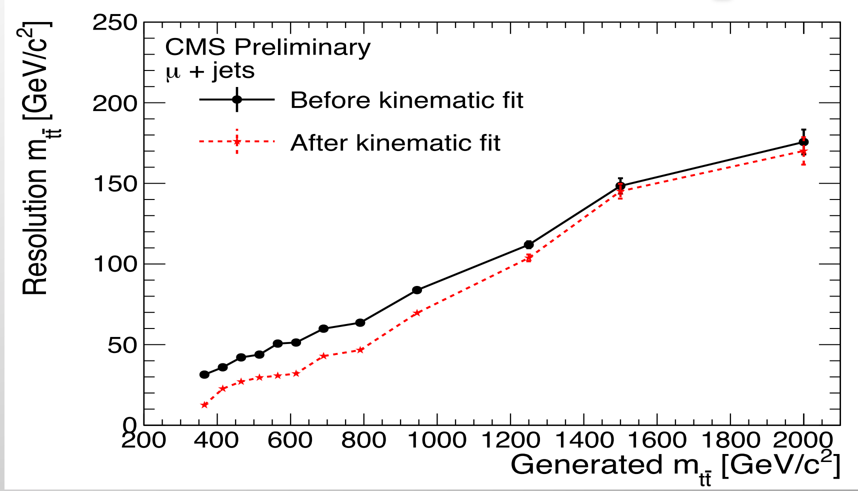
$$\Gamma_{KK}/M_{KK} \simeq 416 \text{ GeV } /1500 \text{ GeV} \simeq 0.27$$

A clean resonance shape is predicted…



(preliminary)

Smearing effect



…becoming only a characteristic shape after simulating the M_{tt} experimental resolution:

V) Conclusions

- The 'warped paradigm', with theoretical motivations, predicts deviations from SM in the 3rd generation sector => *A^b_{FB} , A^t_{FB} = early indications ?*

- We suggest a geometrical RS realization addressing both A^b_{FB} and A^t_{FB}.

- The several constraints on the parameter space render this RS scenario quite predictive on the effects in the $t\bar{t}$ invariant mass ditribution @ LHC.

- This RS framework addressing A^t_{FB} reflects a more generic 'no-lose' thm in the phenomenology of warped models *: a clear signature is expected @ LHC either from KK gluon resonances or from custodian productions.*

- One must wait for more data (Tevatron,LHC) in order to discriminate between the main A^t_{FB} interpretations: Z/W ', KK gluon, Axigluon,…

Back up

Some useful formula's…

$$\cos\theta_t^* = \sqrt{1 + \frac{4m_t^2}{\hat{s} - 4m_t^2}}\ \tanh y_t$$

$$\frac{1}{\mathcal{D}} = \hat{s} - M_{KK}^2 + i\frac{\hat{s}}{M_{KK}^2}\sum_q \Gamma_{KK}^{g^{(1)}\to q\bar{q}} M_{KK}\frac{\beta_q[v_q^2(3-\beta_q^2)]/2 + a_q^2\beta_q^2}{v_q^2 + a_q^2}$$

$$\beta_t = \sqrt{1 - 4m_t^2/\hat{s}}$$

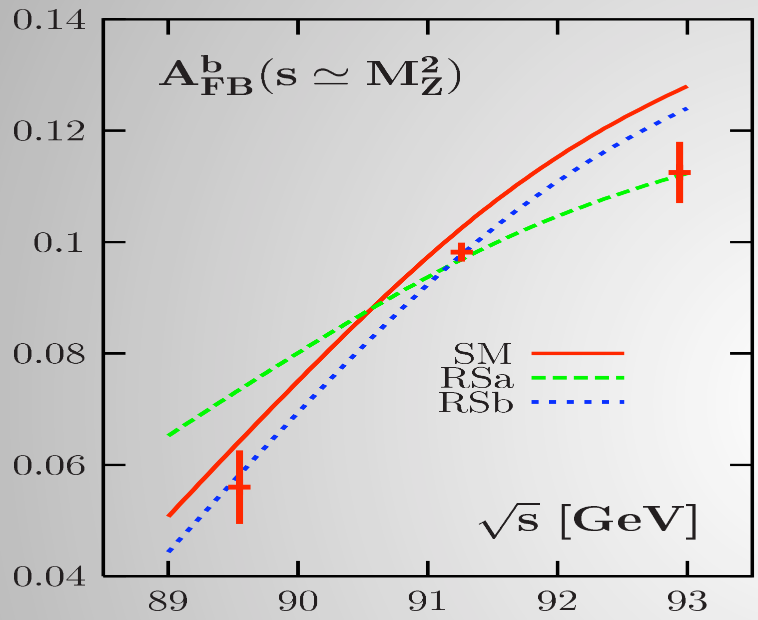
$$\sqrt{\hat{s}_0} \simeq \frac{M_{KK}}{(1 + \Gamma_{KK}^2/M_{KK}^2)^{1/4}}$$

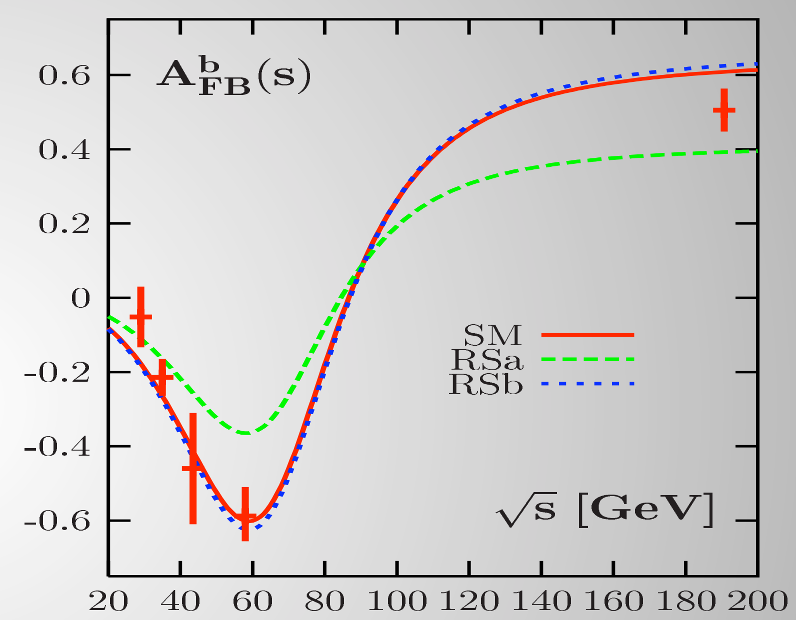
$$\frac{\mathrm{d}\hat{\sigma}_{RS-LO}}{\mathrm{d}\cos\theta_t^*}(\hat{s}) = \frac{\pi\alpha_s^2(\mu_r)\beta_t}{9\hat{s}} \times$$
$$\hat{s}^2|\mathcal{D}|^2\left[8v_q v_t a_q a_t \beta_t \cos\theta^* + (a_q^2 + v_q^2)\left(v_t^2(2-\beta_t^2\sin^2\theta^*) + a_t^2\beta_t^2(1+\cos^2\theta^*)\right)\right]$$

$$\frac{\mathrm{d}\hat{\sigma}_{inter.-LO}}{\mathrm{d}\cos\theta_t^*}(\hat{s}) = \frac{\pi\alpha_s^2(\mu_r)\beta_t}{9\hat{s}} 4\hat{s}\mathrm{Re}(\mathcal{D})\left[v_q v_t\left(1-\frac{1}{2}\beta_t^2\sin^2\theta^*\right) + a_q a_t \beta_t \cos\theta^*\right]$$

$$\left(\quad \frac{\mathrm{d}\hat{\sigma}_{SM-LO}}{\mathrm{d}\cos\theta_t^*}(\hat{s})\Big|_{q\bar{q}} = \frac{\pi\alpha_s^2(\mu_r)\beta_t}{9\hat{s}}\left\{2-\beta_t^2\sin^2\theta^*\right\} \quad \right)$$

Global A^b_{FB} fit @ and off the Z pôle :





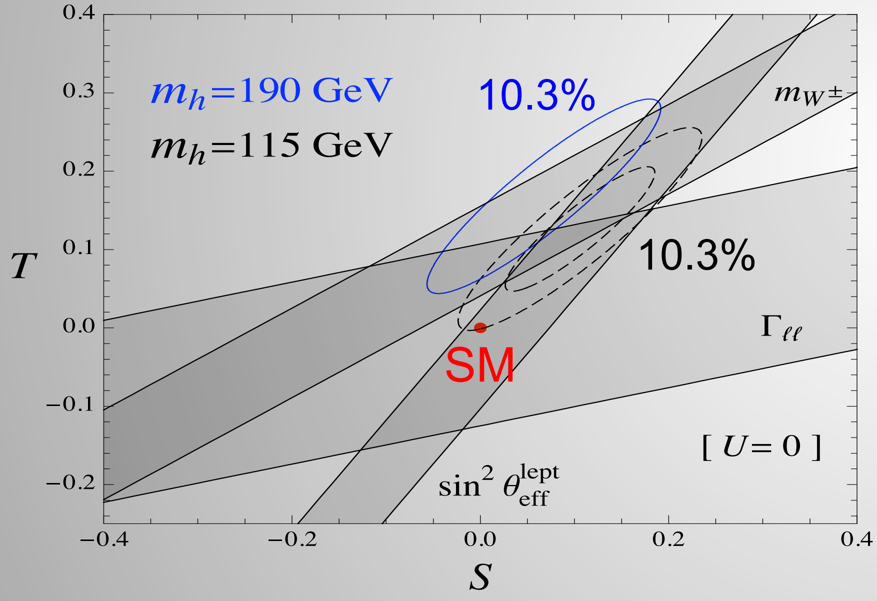
SM : $\chi^2 = 24$ RSa : $\chi^2 = 20$ RSb : $\chi^2 = 14$

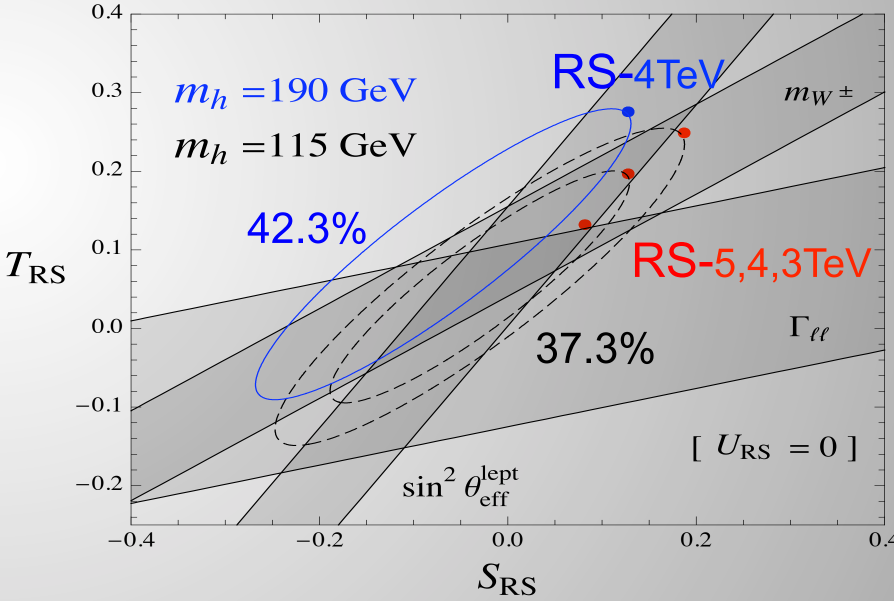
b_R under $SU(2)_L \times SU(2)_R \times U(1)_X$: $\begin{cases} Q_X = (B-L)/2 \Rightarrow I_R^3 = -1/2 & \text{RSa} \\ Q_X = -5/6 \Rightarrow I_R^3 = +1/2 & \text{RSb} \end{cases}$

Improved goodness-of-fit

EW observables are expressed in terms of oblique parameters encoding the New Physics...

$$S_{\rm RS} \simeq 2\pi \left(\frac{2.4v}{M_{KK}}\right)^2 \qquad T_{\rm RS} \simeq k\pi^2 R_c \frac{\tilde{g}^2}{8e^2}\frac{\tilde{M}^2}{k^2}\left(\frac{2.4v}{M_{KK}}\right)^2$$





p-value 10.3% ⇔ $\chi^2/11 = 1.56$

p-value 37.3% ⇔ $\chi^2/10 = 1.08$

Best-fit Higgs mass

- RS fit can be better for any m_h>115GeV (e.g. m_h=190GeV => h->Z^0Z^0)

- for m_h= 500 GeV
  - p-value can be @ 25.3% in RS if M_{KK}= 4 TeV
  - p-value is only @ 2.5 10^{-9} in SM
  - m_h excluded in gauge-Higgs unification & SUSY

=> the discovery of a heavy Higgs would constitute a sign for RS

- the best-fit m_h value is possibly larger than the LEP2 direct limit of 115GeV

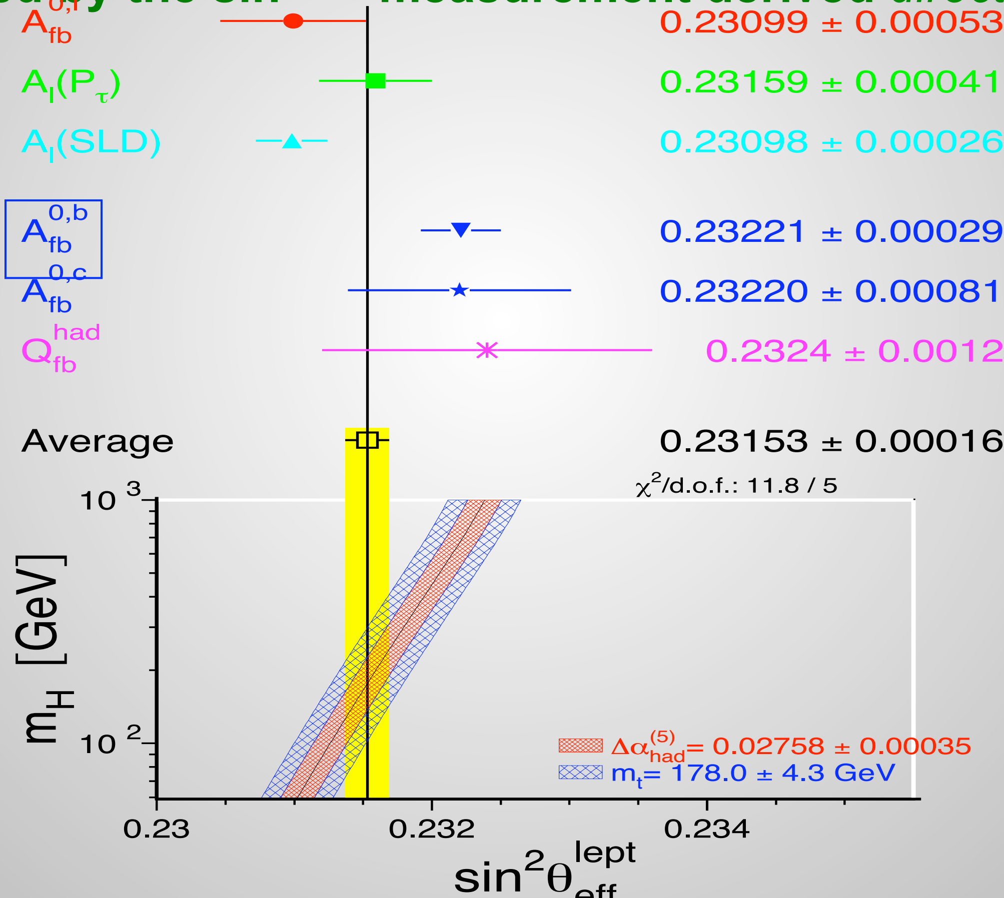
in contrast with the SM where the best-fit m_h is 76^{-24}_{+33} GeV
(getting even smaller by excluding A^b_{FB})

Better quality of fit in RS than in SM cause..

1)positive contribution T_{RS} *(custodial symmetry breaking)*

2)SM fit degraded by the $\sin^2\theta_W$ measurement derived *directly* from A^b_{FB} :

SM →



Problems/Solutions in the Higgs boson sector

a) Quantum instability of the Higgs mass: $\delta m_h^2 \propto \Lambda_{NP}^2$

~> Supersymmetry (MSSM): $\delta m_h^2 \approx \tilde{m}^2 \approx (10^2\, GeV)^2$ as no quadratic dvg.

~> Extra Dimensions (ADD,RS): δm_h^2 protected by $\Lambda_{NP} < M_{grav} \approx TeV$

(Higgsless): models without Higgs boson !

~> Composite Higgs (MHCM): δm_h^2 protected by $\Lambda_{NP} = \Lambda_{IR} \approx TeV$

[& possibly till Λ_{NP} via a global symmetry]

b) Quantum instability of the Higgs quartic coupling λ

~> Supersymmetry (MSSM): SUSY => $\lambda = g^2$ protects λ

~> Extra Dimensions (gauge-Higgs unif.): GAUGE SYM. => $\lambda = g^2$ protects λ

(Higgsless): no high-energy Higgs potential

c) EW Symmetry Breaking dynamics

~> Supersymmetry (mSUGRA): EWSB triggered by negative Higgs mass induced radiatively (via top quark loop)

~> Composite Higgs (MHCM): EWSB triggered by negative Higgs mass induced radiatively (via top quark loop)

~> Extra Dimensions (Higgsless): SB by field Boundary Conditions & KK masses for fermions/bosons

So the main approaches towards the Higgs questions are SUSY or ED like

+ renew of interest for ED-type scenarios:

EXP. – no discovery of superpartners @ LEPII (nor Tevatron Run II)

TH. – AdS/CFT correspondance (98') => calculability of EW observables (03') in Composite Higgs scenarios (84')