Examining Z’ decays to 3rd gen. fermions (b, t, τ)

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arXiv:1006.2845

Outline

- Discovery of a Z' - Early and Late LHC
- Identification of a Z'
  - $t\bar{t}$ and $b\bar{b}$ channel
  - $\tau\tau$ channel
  - Forward Backward Asymmetry
- Summary

Deviations from SM

- $N(\nu) = 2.985 \pm 0.008$ [1]
- $A_{FB}^t(SM) = 5.0 \pm 1.5\%$ $A_{FB}^t(Teva) = 19.3 \pm 6.9\%$ [2]
- $A_{FB}^b(SM) = 10.33 \pm 0.07\%$ $A_{FB}^b(LEP) = 9.92 \pm 0.16\%$ [3]
- Muon (g-2): (SM) 4511.07±0.74 (BNL E821) 4509.04±0.09 [3]
- Extra neutral gauge boson, Z', possible!
- Non-Universal Couplings?

[1] See Erler and Langacker, PhysRevLett.84.212
[2] See Cao, Heng and Yang, PhysRevD.81.014016
[3] See Erler, et al, JHEP 0908:017

Current Limits

- FNAL, SLAC, CERN, JLab, LEP, Tevatron...

Z'	$M_{Z'}$ [GeV]			
	EW (this work)	CDF	DØ	LEP 2
Z_χ	1,141	892	640	673
Z_ψ	147	878	650	481
Z_η	427	982	680	434
Z_I	1,204	789	575	
Z_S	1,257	821		
Z_N	623	861		
Z_R	442			
Z_{LR}	998	630		804
$Z_{\not{L}}$	(803)	(740)		
Z_{SM}	1,403	1,030	780	1,787
Z_{string}	1,362			

Erler, et al, JHEP 0908:017

$L=1.08\ fb^{-1}\ e^+e^-$

$L=1.21\ fb^{-1}\ \mu^+\mu^-$

Model	e^+e^-	$\mu^+\mu^-$	$\ell^+\ell^-$
Z'_{SSM}	1.70 (1.70)	1.61 (1.61)	1.83 (1.83)
G	1.51 (1.50)	1.45 (1.44)	1.63 (1.63)

	E_6 Z' Models					
Model/Coupling	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ
Mass limit [TeV]	1.49	1.52	1.54	1.56	1.60	1.64

ATLAS Collaboration, CERN-PH-EP-2011-123

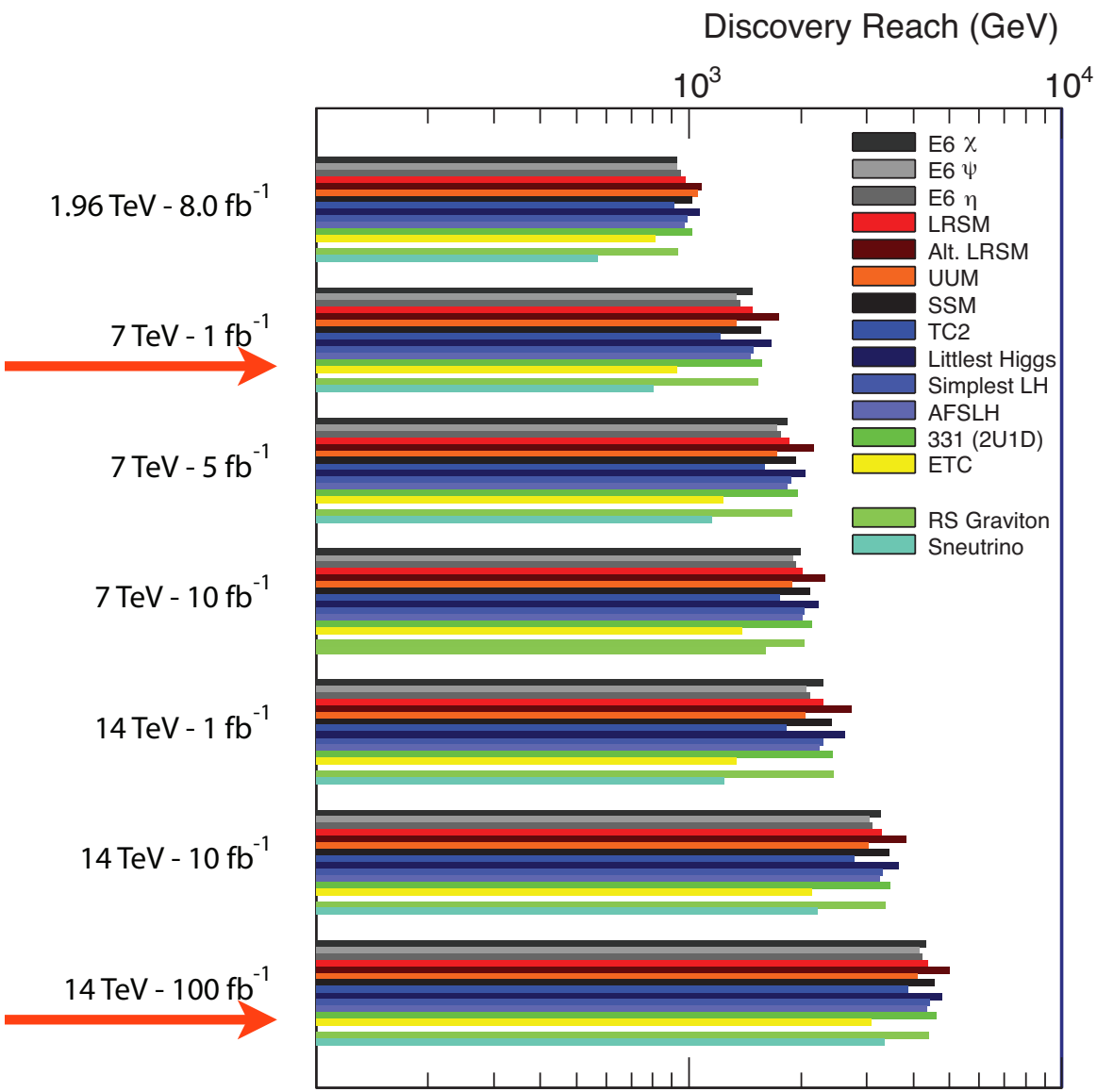
Theory Estimate ($\mu\mu$ only):

SSM	1605 GeV
E6 χ	1517 GeV
E6 ψ	1385 GeV
E6 η	1429 GeV

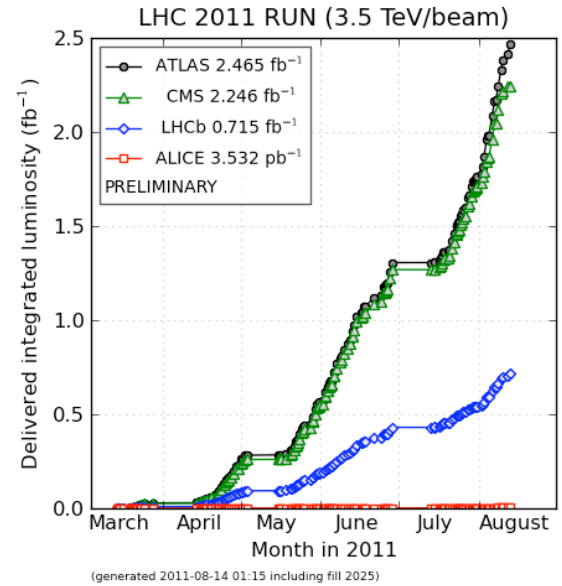
A Plethora of Models

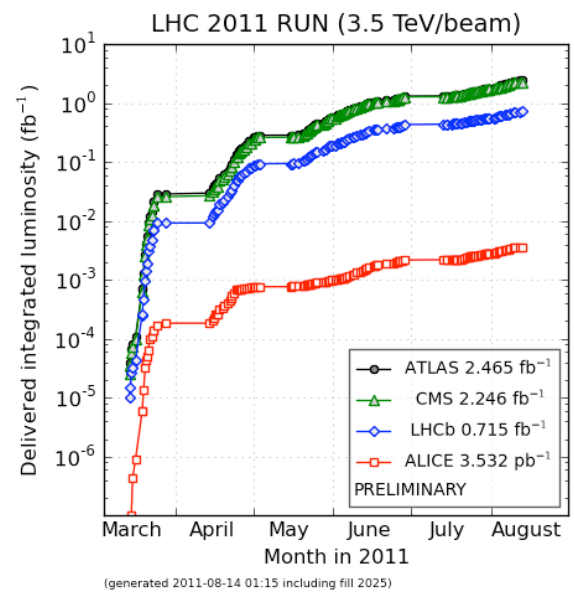
- Non-exhaustive list:
  - GUT Motivated - E6 χ,η,ψ (couplings ~ θ_{E6})
  - Left Right Symmetric (couplings ~ g_R/g_L)
  - 3-3-1 Model
  - Little Higgs (variants)
  - Topcolor & Technicolor (couplings ~ θ_{TC2}, θ_{ETC})
  - Un-unified Model (couplings ~ θ_{UUM})
- Topcolor, Technicolor, Un-unified models - non-universal couplings

LHC Discovery Potential



http://lpc.web.cern.ch/lpc/lumiplots.htm





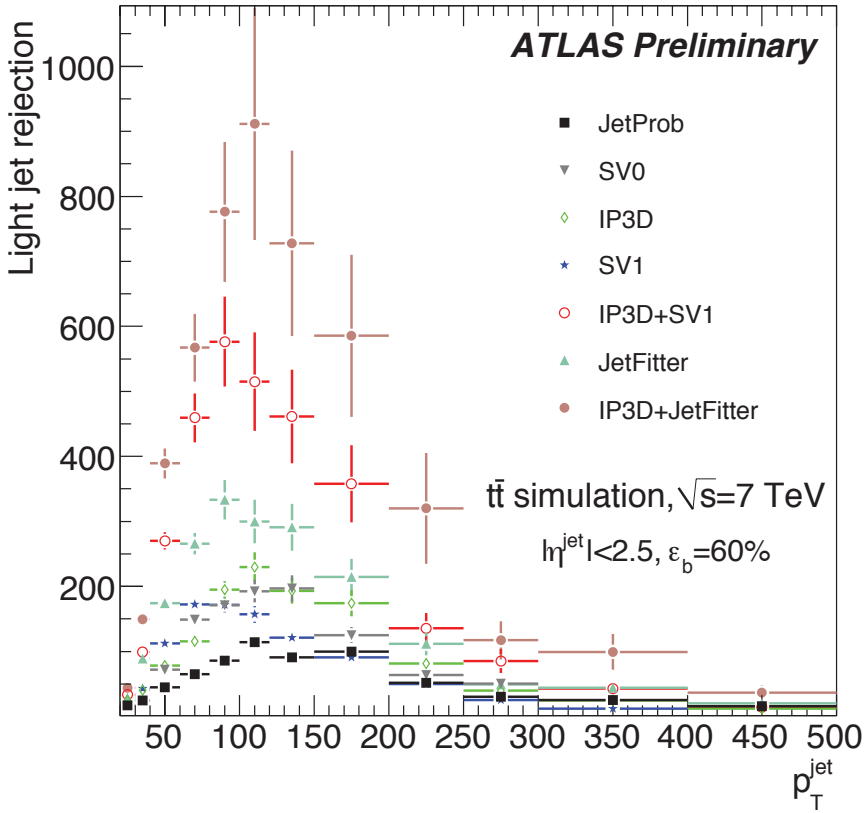
Diener, Godfrey & Martin, arXiv:0910.1334 [hep-ph]

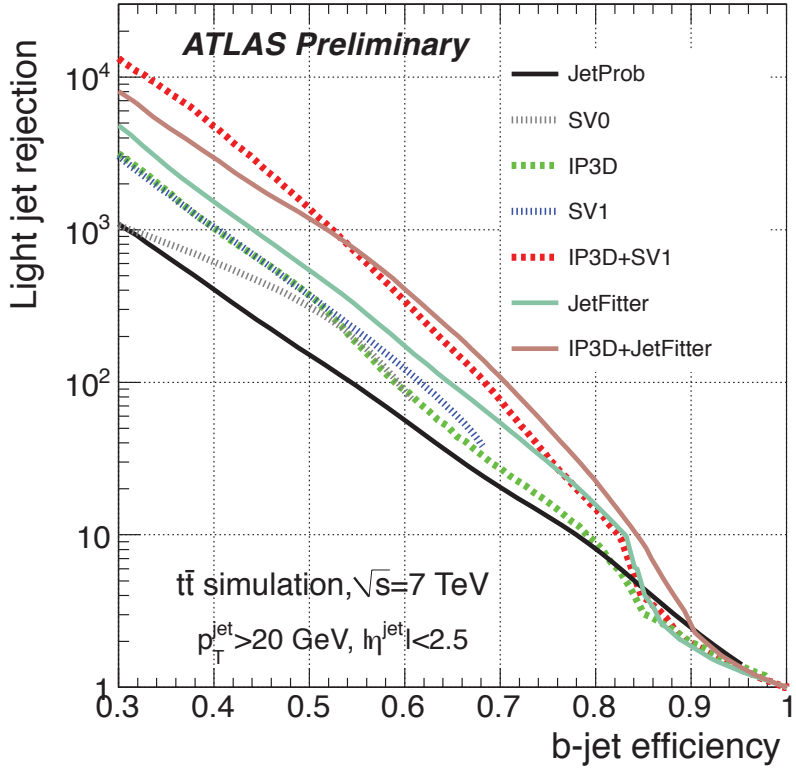
Identify with 3rd Gen Fermions

- Motivation: Uniquely identify non-universal models
- Benefits:
  - Access coupling info, unavailable otherwise
  - Useful for global fit
- Difficulties:
  - ID is challenging, low statistics
  - Large backgrounds
- Analysis assumes $M_{Z'}$, $\Gamma_{Z'}$ known from $\mu^+\mu^-$ measurements
- Calculations done with MC w/ weighted events, at $\sqrt{s}$ = 14 TeV, L = 100 fb^{-1}

Tagging - b-quark

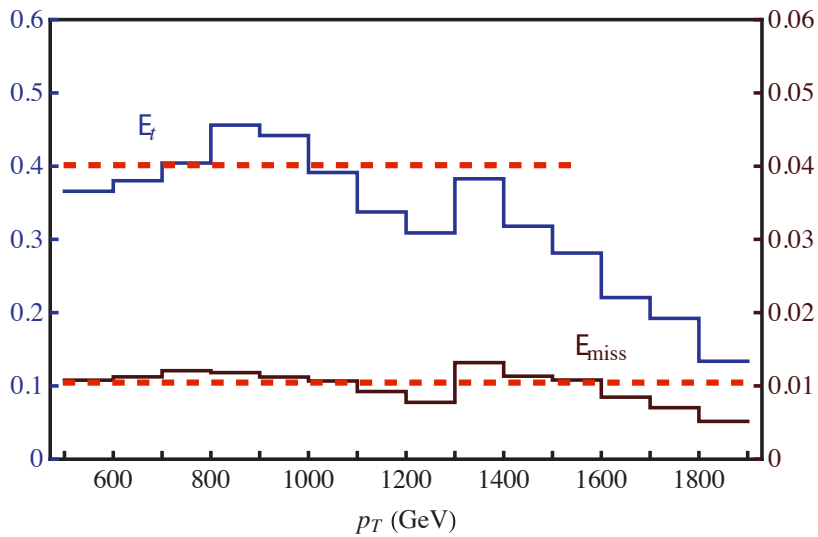
- ε_b~60%, ε_j<1% fake
- Worse fake rate for higher p_T

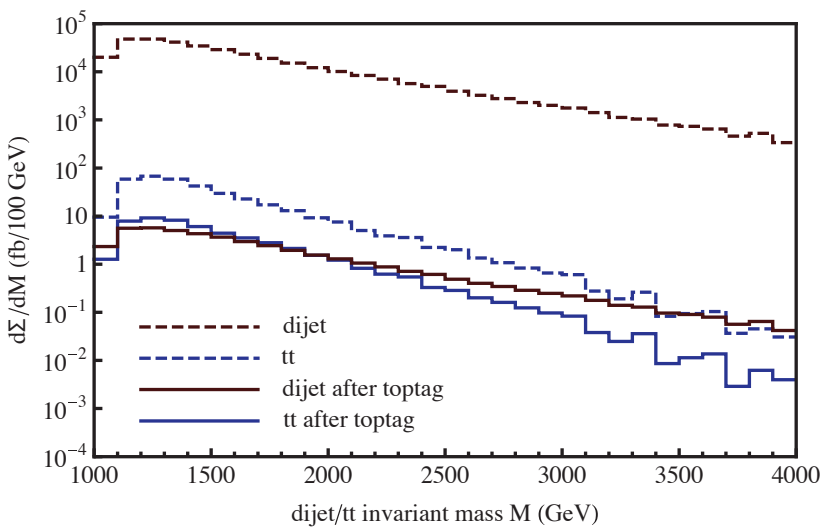




The ATLAS Collaboration, ATLAS-CONF-2011-102

Tagging - t-quark





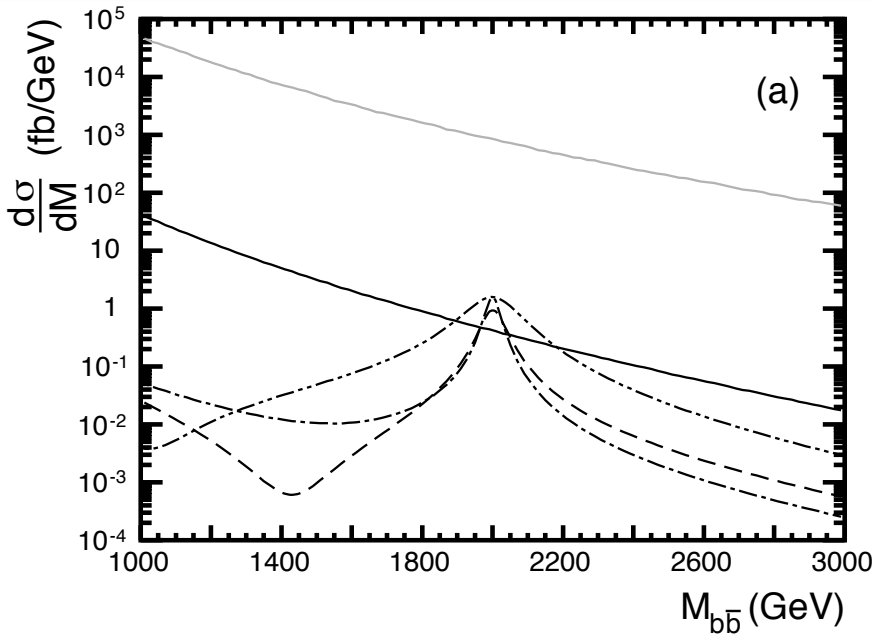
Kaplan, Rehermann, Schwartz and Tweedie, Phys. Rev. Lett.101:142001 (2008)

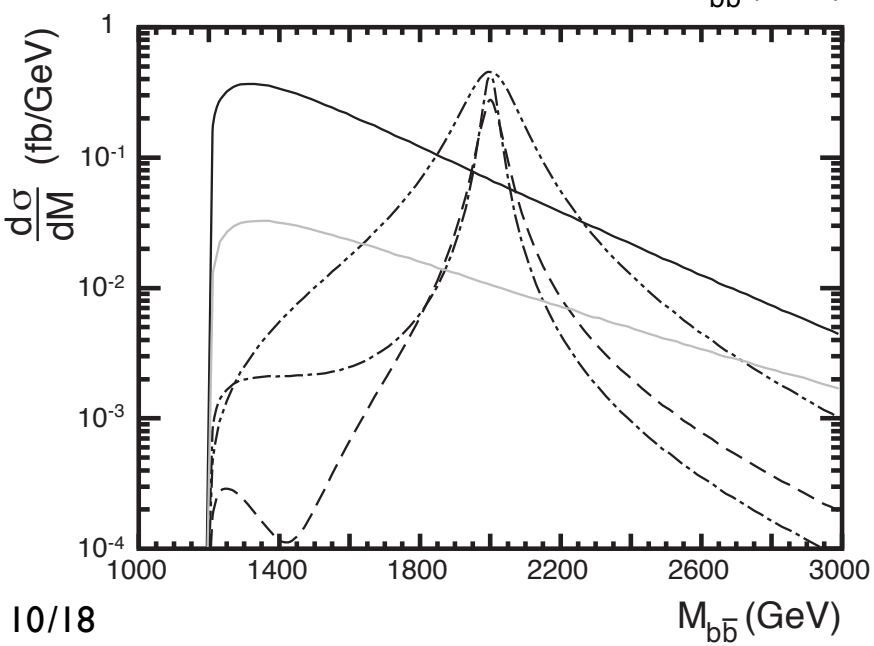
- Traditional: $t\bar{t} \rightarrow b\bar{b}jj l\nu$
- High p_T top → fully hadronic
  - fully hadronic BR: 46%
  - semi leptonic BR: 30%
- ε_t ~40%, ε_j ~1%
- New methods?

Current Dilepton & Semi-Leptonic:
ε_{tt} = 1-2% (low p_T)

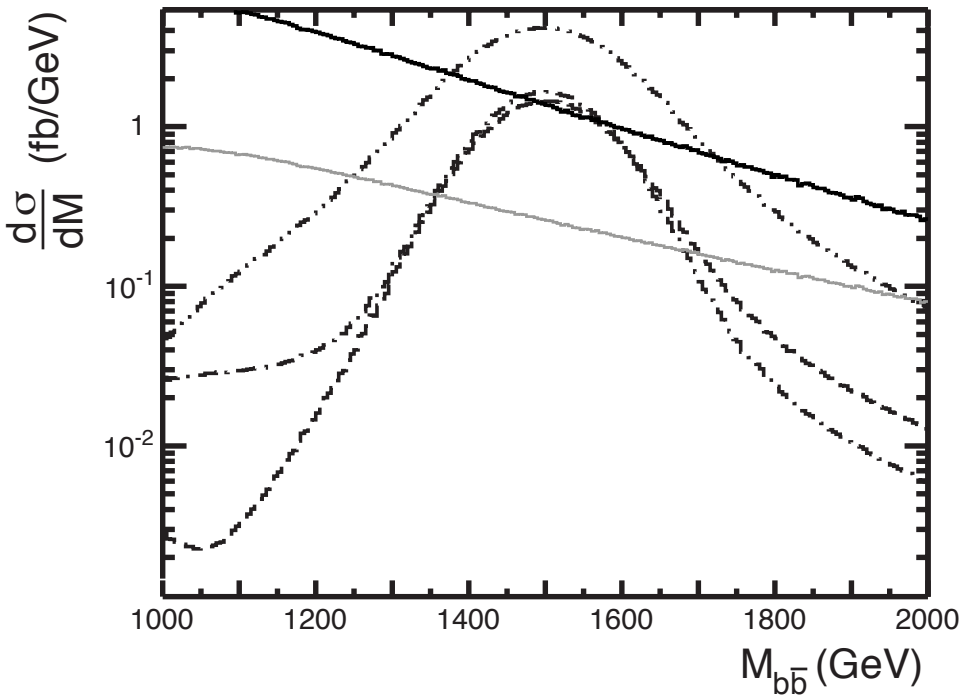
The ATLAS Collaboration, ATLAS-CONF-2011-100

A Signal in the Background

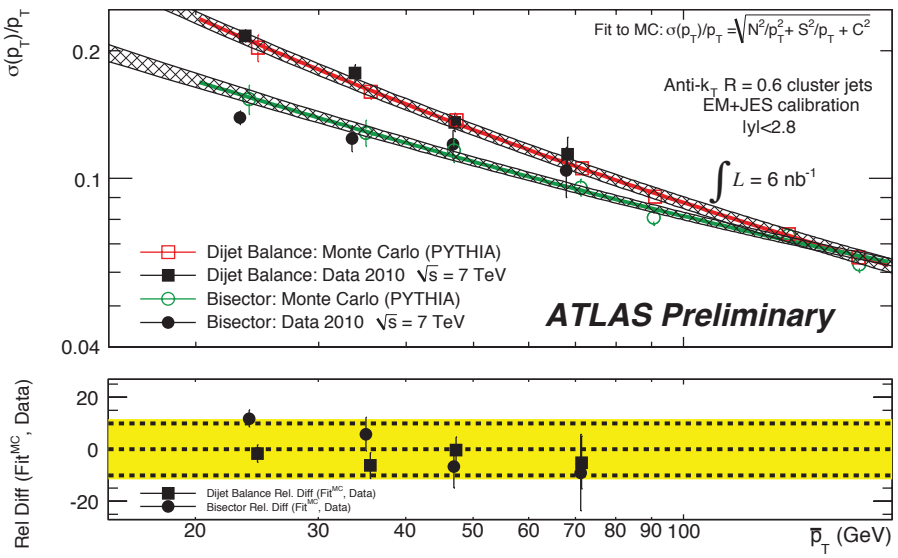




- $p_T > 0.3 M_{Z'}$ improves S/B
- Invariant mass window:
  - $|M - M_{Z'}| < 2.5 \Gamma_{Z'}$



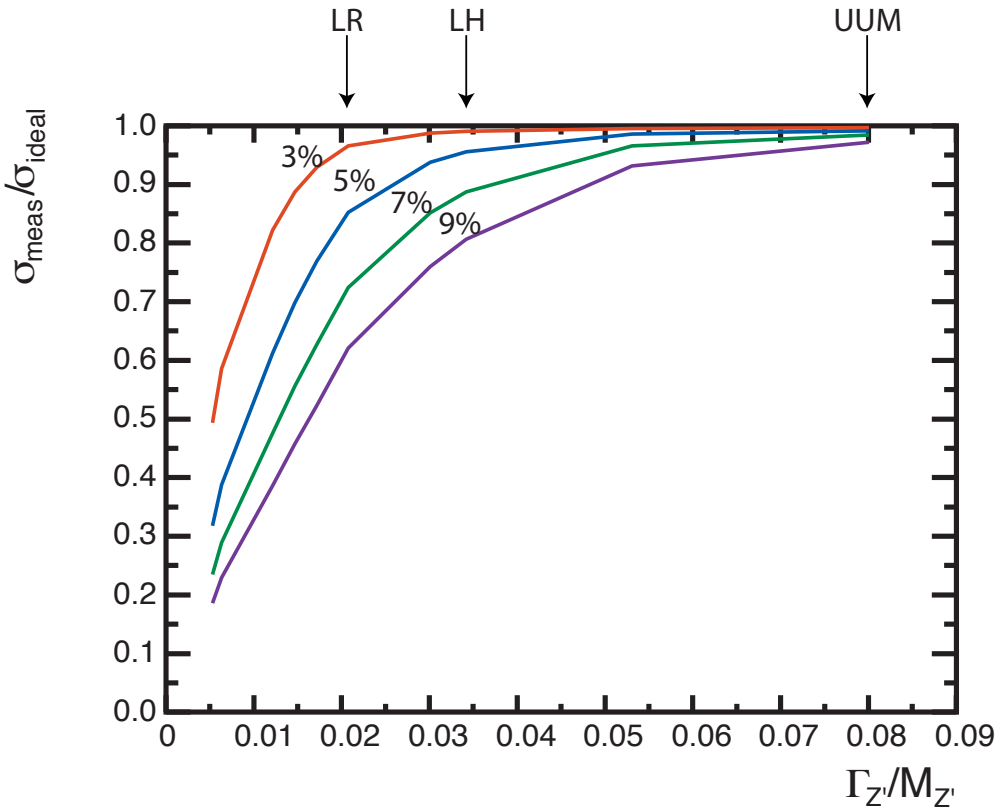
Detector Capabilities



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-054/

- Assume no change to invariant mass window
- Still maintain event rate for wider models

- Currently ~7% resolution
- May achieve 5% res.
- Measured Signal/Ideal:

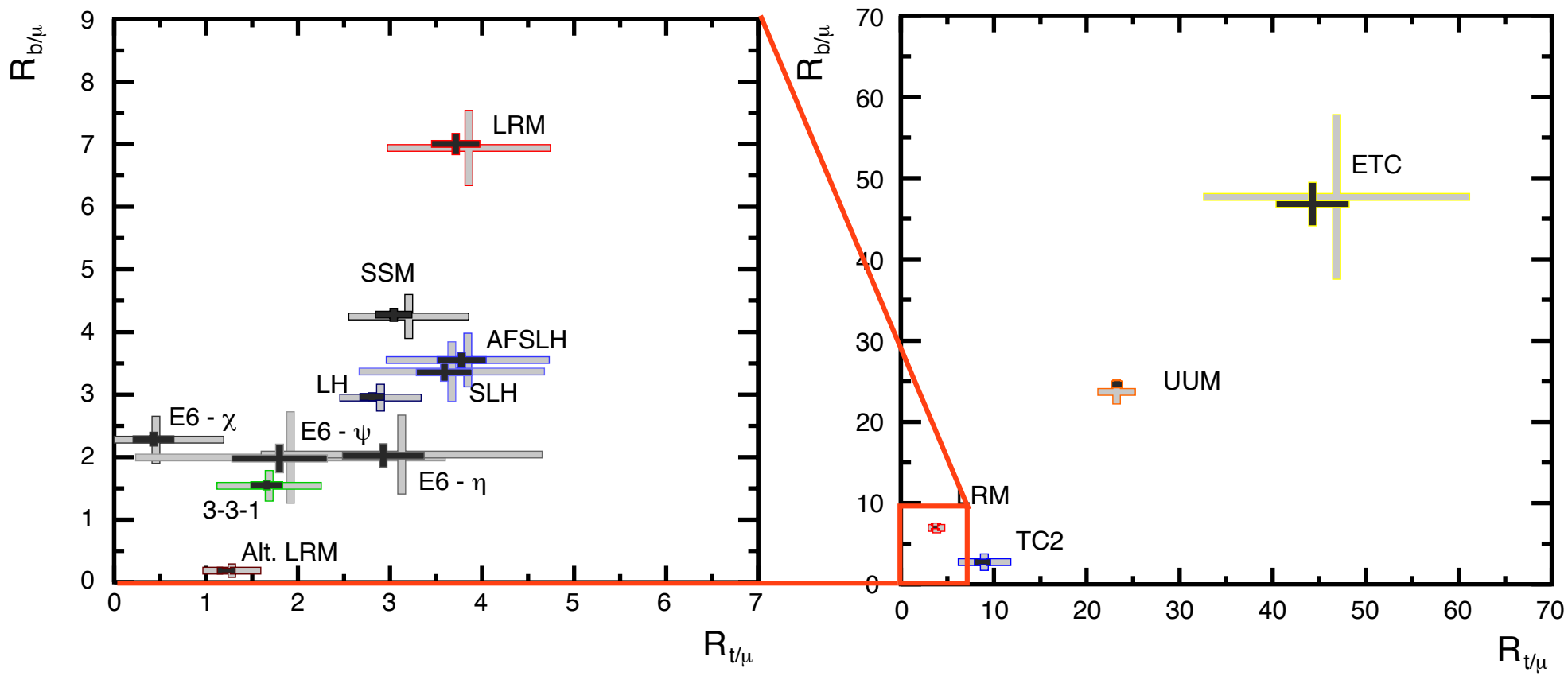


Ratio of events: $R_{t/\mu}$ vs $R_{b/\mu}$

- $R_{t/\mu} \sim K(R_t^2+L_t^2)/(R_\mu^2+L_\mu^2)$
- $R_{b/\mu} \sim K(R_b^2+L_b^2)/(R_\mu^2+L_\mu^2)$

$\varepsilon_{tt} = 0.075$, $\varepsilon_{jj} = 1/100^2$, $\sigma_t=5\%$
$\varepsilon_{bb} = 0.36$, $\varepsilon_{jj} = 1/100^2$, $\sigma_b=5\%$
$\varepsilon_{mm} = 0.92$, $\sigma_\mu=3\%$

$M_{Z'}$ = 1500 GeV (dark), 2500 GeV (light)



Diener, Godfrey and Martin, Phys.Rev.D83:115008,2011

Parameterized Couplings

$$\gamma_L^\ell = \frac{(\hat{g}^\ell_{L\,2})^2}{(\hat{g}^\ell_{L\,2})^2 + (\hat{g}^\ell_{R\,2})^2} \qquad \gamma_L^q = \frac{(\hat{g}^q_{L\,2})^2}{(\hat{g}^\ell_{L\,2})^2 + (\hat{g}^\ell_{R\,2})^2} \qquad U = \left(\frac{\hat{g}^u_{R\,2}}{\hat{g}^q_{L\,2}}\right)^2 \qquad D = \left(\frac{\hat{g}^d_{R\,2}}{\hat{g}^q_{L\,2}}\right)^2$$

M. Cvetic and P. Langacker, Phys. Rev. D46, 4943 (1992)

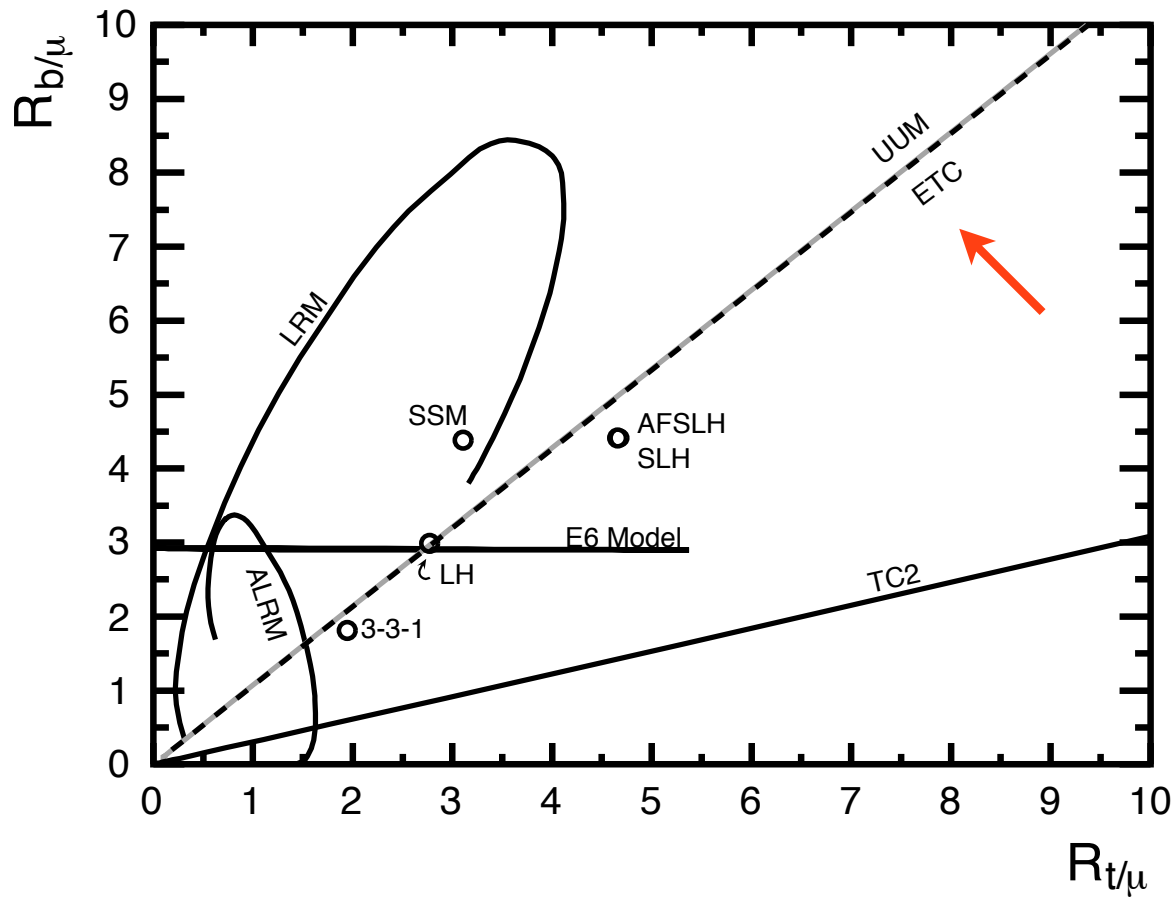
- $R_{t/\mu} \sim K(R_t^2+L_t^2)/(R_\mu^2+L_\mu^2)$
  - $R_{t/\mu} \sim K\,\gamma_L^q\,(U+1)$
- $R_{b/\mu} \sim K(R_b^2+L_b^2)/(R_\mu^2+L_\mu^2)$
  - $R_{b/\mu} \sim K\,\gamma_L^q\,(D+1)$

A_{FB}	$\frac{.387(2\gamma_L^l - 1)\times(1-.753\tilde{U}-.247\tilde{D})}{1+.684\tilde{U}+.316\tilde{D}}$
r_{y_1}	$1.796\frac{1+.652\tilde{U}+.348\tilde{D}}{1+.736\tilde{U}+.264\tilde{D}}$
$A_{FB\,y_1}$	$.726\frac{1-.731\tilde{U}-.269\tilde{D}}{1-.769\tilde{U}-.231\tilde{D}}$
B_{qq}	$\gamma_L^l(2+\tilde{U}+\tilde{D})$
$r_{l\nu W}$	$0.067\gamma_L^l$
$R_{Z'Z}$	$\frac{10^{-3}(7.55+.924\tilde{U}+0.098\tilde{d})}{1+.684\tilde{U}+.316\tilde{D}}$
$R_{Z'W}$	$\frac{24.53\times 10^{-3}}{1+.684\tilde{U}+.316\tilde{D}}$
$R_{Z'\gamma}$	$\frac{5.38\times 10^{-3}(1+.896\tilde{U}+.104\tilde{D})}{1+.684\tilde{U}+.316\tilde{D}}$

Cvetic & Godfrey, arXiv.org:hep-ph/9504216

Varying Model Parameters

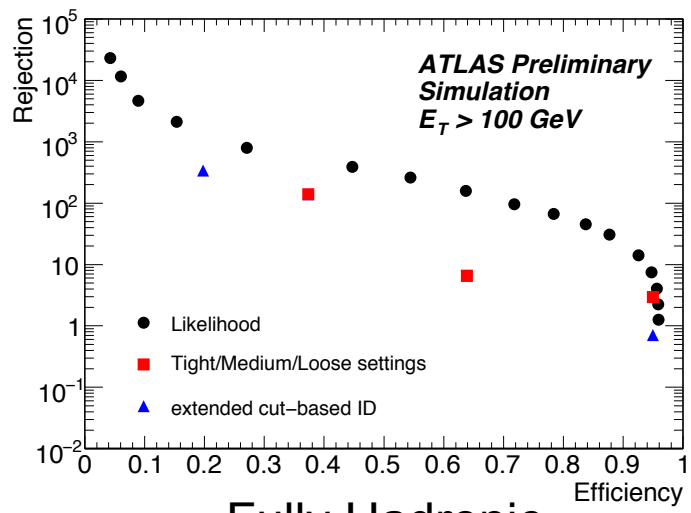
- Only measurement to depend on mixing angle from UUM, ETC and TC2 models



$R_{\tau/\mu}$ - Generation Universality

- Directly tests generation universality
- Use collinear approximation for $M_{\tau\tau}$

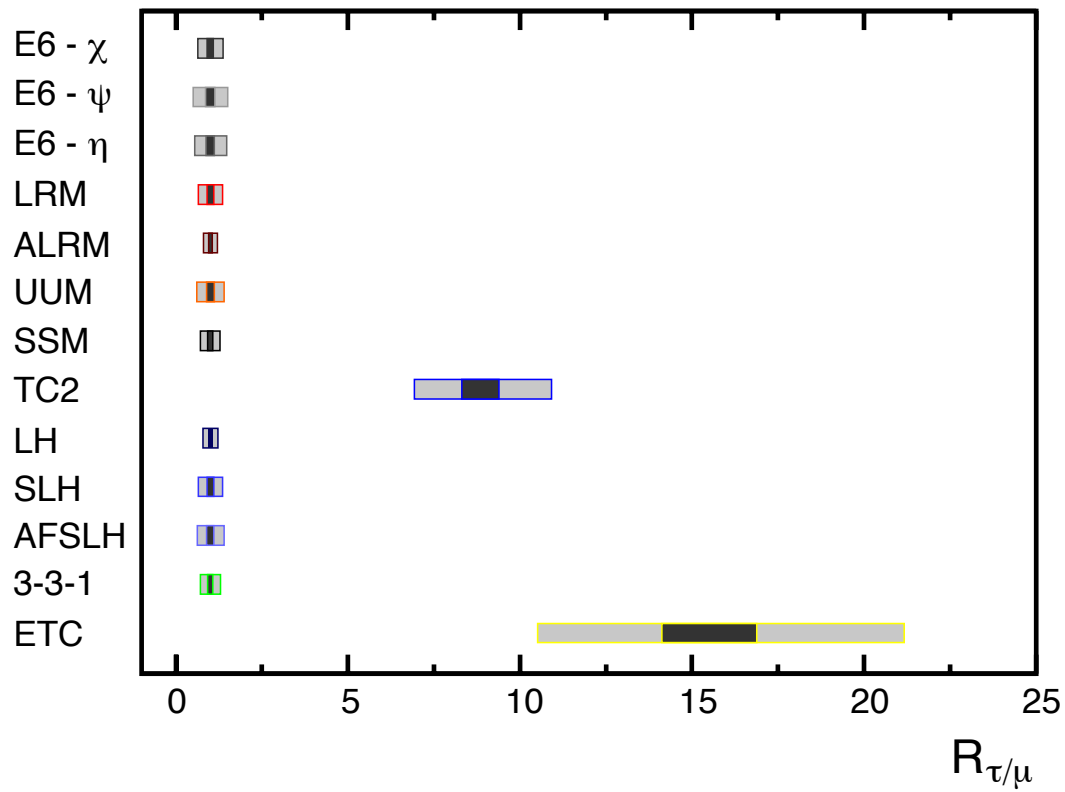
The ATLAS Collaboration, ATL-PHYS-PUB-2010-001



Fully Hadronic

$\varepsilon_{\tau,1p} = 0.31$, $\varepsilon_{\tau,3p} = 0.34$, $\varepsilon_j < 0.0025$

$M_{Z'}$ = 1500 GeV (dark), 2500 GeV (light)



- O(10%) invariant mass resolution not included *

*** 10% cited by Plehn, et al. Phys.Rev.D61:093005,2000**
~7% cited by Mellado, et al. Phys.Lett.B611:60-65,2005
~8% cited in CERN-OPEN-2008 detector paper (pg 1299)

Forward Backward Asym. - A_{FB}

- Improve systematics by using pseudorapidity
- Forward: $|\eta_f| > |\eta_{\bar{f}}|$

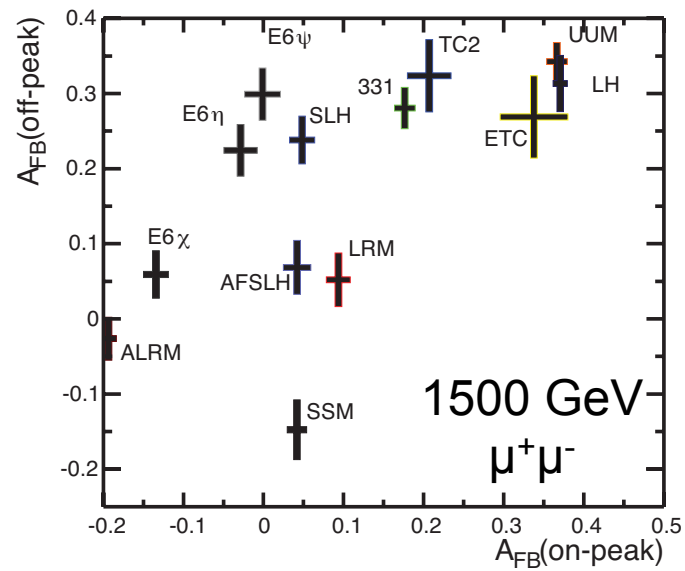
$$\beta = \frac{x_a - x_b}{x_a + x_b}$$

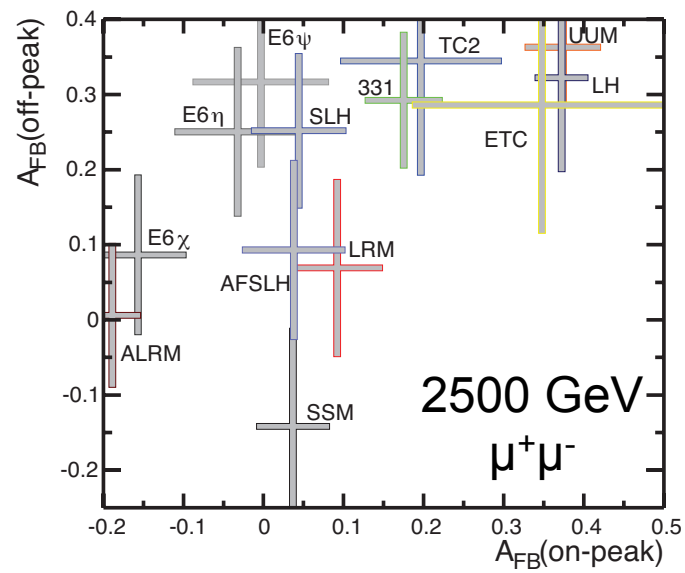
$$\eta_f = \frac{1}{2}\ln\frac{1+\beta}{1-\beta} + \frac{1}{2}\ln\frac{1+z}{1-z} \qquad Y = \frac{1}{2}\ln\frac{1+\beta}{1-\beta}$$

$$\eta_{\bar{f}} = \frac{1}{2}\ln\frac{1+\beta}{1-\beta} - \frac{1}{2}\ln\frac{1+z}{1-z} \qquad Z = \frac{1}{2}\ln\frac{1+z}{1-z}$$

$$\eta_f = Y + Z \qquad \eta_{\bar{f}} = Y - Z$$

$|Y + Z| > |Y - Z|$ when both Y and Z are like signed. ("Forward")
$|Y + Z| < |Y - Z|$ when Y and Z are opposite signed. ("Backward")
recalling that Y and Z are signed the same as $y_{Z'}$ and z.





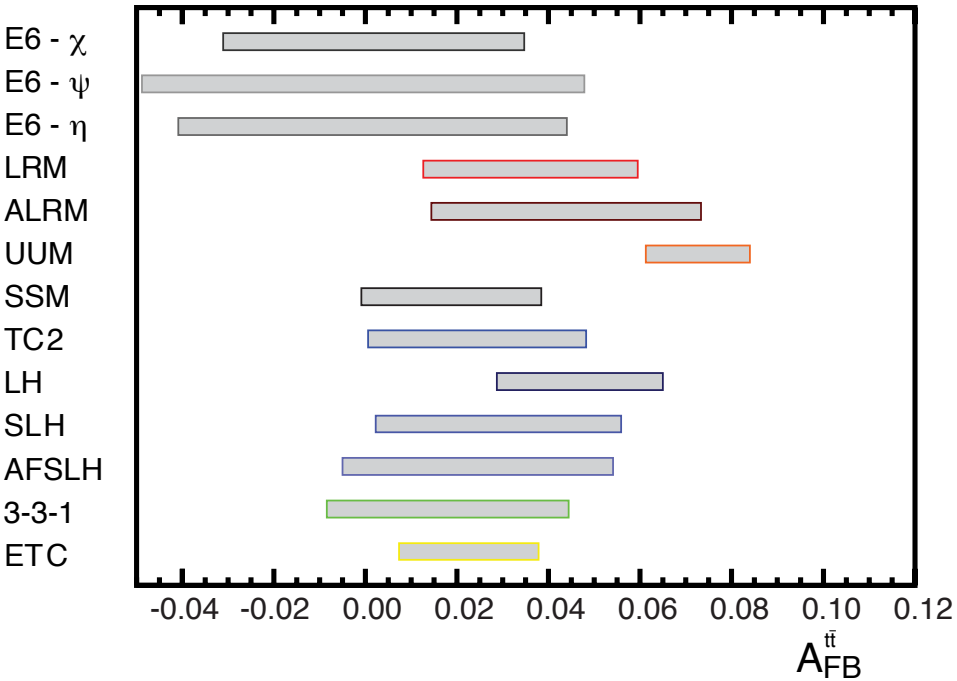
Diener, Godfrey & Martin, Phys.Rev.D80:075014

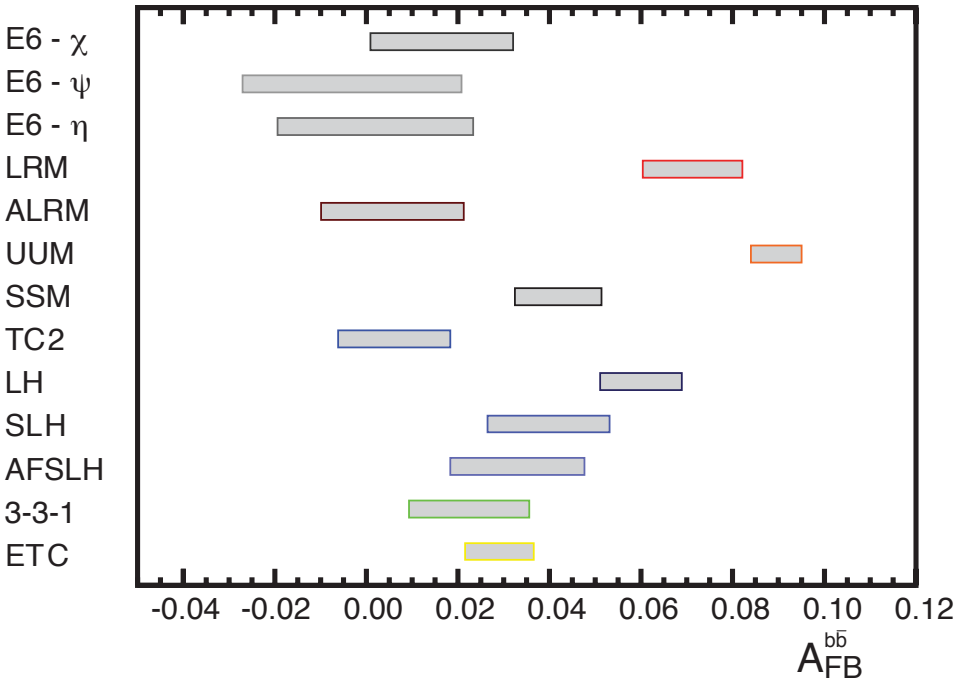
A_{FB} - Top and Bottom

- Include $\sigma_{t,b}$=5%

$M_{Z'}$ = 1500 GeV

ε_{tt} = 0.075, ε_{jj} = 1/100^2
ε_{bb} = 0.36, ε_{jj} = 1/100^2





- Heavy Quark and Dijet background do not contribute at tree level

Diener, Godfrey and Martin, Phys.Rev.D83:115008,2011

Summary

- LHC can be more than “Discovery Machine”
  - 4-5 TeV discovery reach
  - Fit of experiment to Monte Carlo up to 2-2.5 TeV
  - Use wide variety of observables
- Third Gen. gives important insight
  - Necessary to determine universal couplings