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DPF 2009

Identification of Extra Neutral Gauge Bosons at the LHC

Ross Diener, Travis Martin & Stephen Godfrey

Carleton University/TRIUMF

Some reviews on Z' 's:

- T. Rizzo, hep-ph/0610104
- A. Leike, Phys. Rept. 183, 193 (1989)
- M. Cvetic & S. Godfrey, hep-ph/9504216

New Physics at TeV ?

- Believe standard model is low energy effective theory & expect some form of new physics to exist beyond the SM

Many, many models:

- Extended gauge sectors
  - Extra U(1) factors: $E_6 \rightarrow SU(5) \times U(1)_\chi \times U(1)_\psi$
  - Left-Right symmetric model: $SU(2)_L \times SU(2)_R \times U(1)$
- Little Higgs $W_H^\pm \quad Z_H \quad B_H$
- Extra dimensions (ADD, RS, UED…): KK excitations
  - ADD: Graviton tower exchange effective operators:
  - Randall-Sundrum Gravitons: Discrete KK graviton spectrum
- SUSY & SUSY GUTS
- Technicolour
- Topcolour

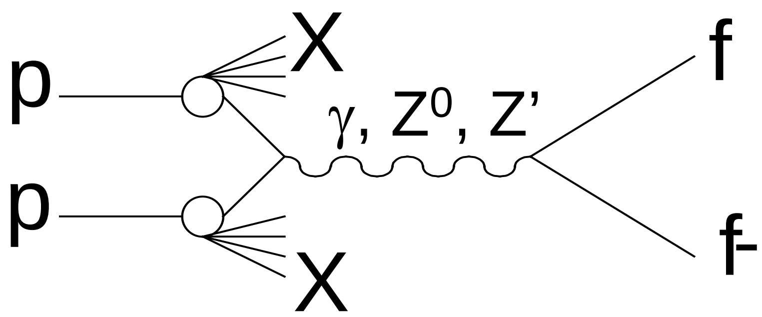
New s-channel Resonances

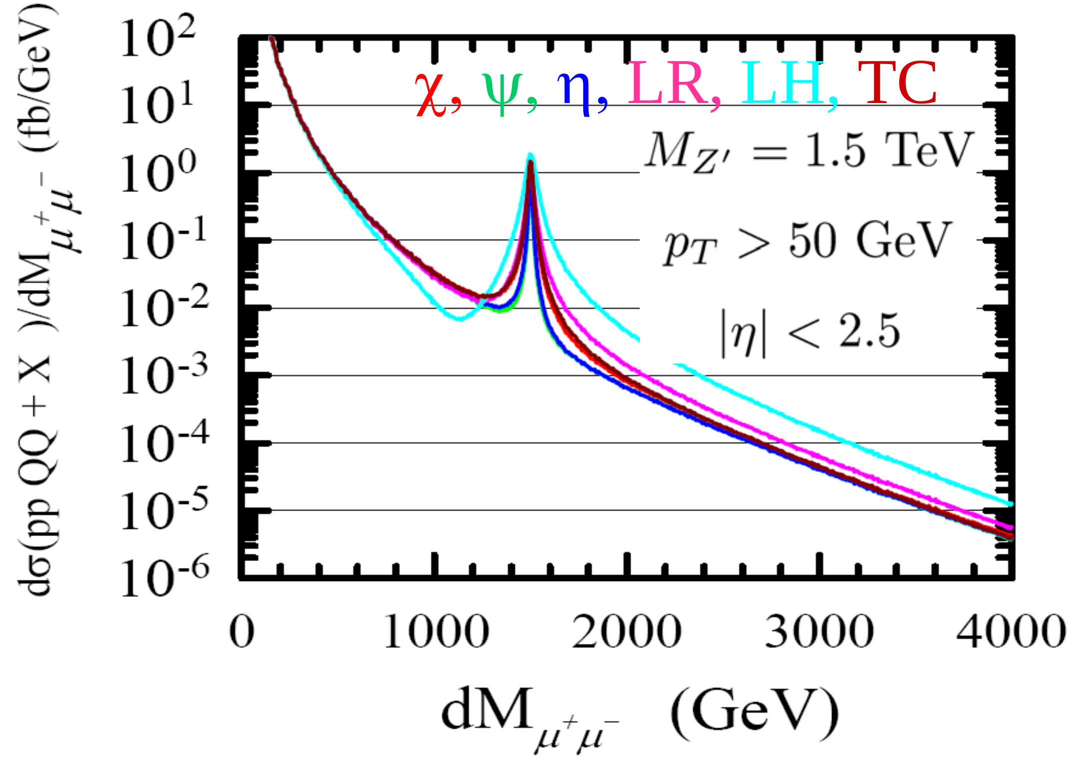
What do these models have in common?

- Almost all of these models have new s-channel structure at ~TeV scale:
    - Z' in string inspired models
    - Z', W' in extended gauge sectors
    - Z_R, W_R in left-right symmetric models
    - Z_H, W_H in Little Higgs Models
    - Z_{KK}, γ_{KK}, W_{KK}, in theories with extra dimensions

How do we distinguish the models?

Z' Production at Hadron Colliders





$$\frac{d\sigma}{dy\,dM\,d\cos\theta^*} = \frac{2\pi\alpha_{em}^2 x_A x_B}{3M^3}\sum_q [(1+\cos^2\theta^*)S_q G_q^+ + 2\cos\theta^* A_q G_q^-]$$

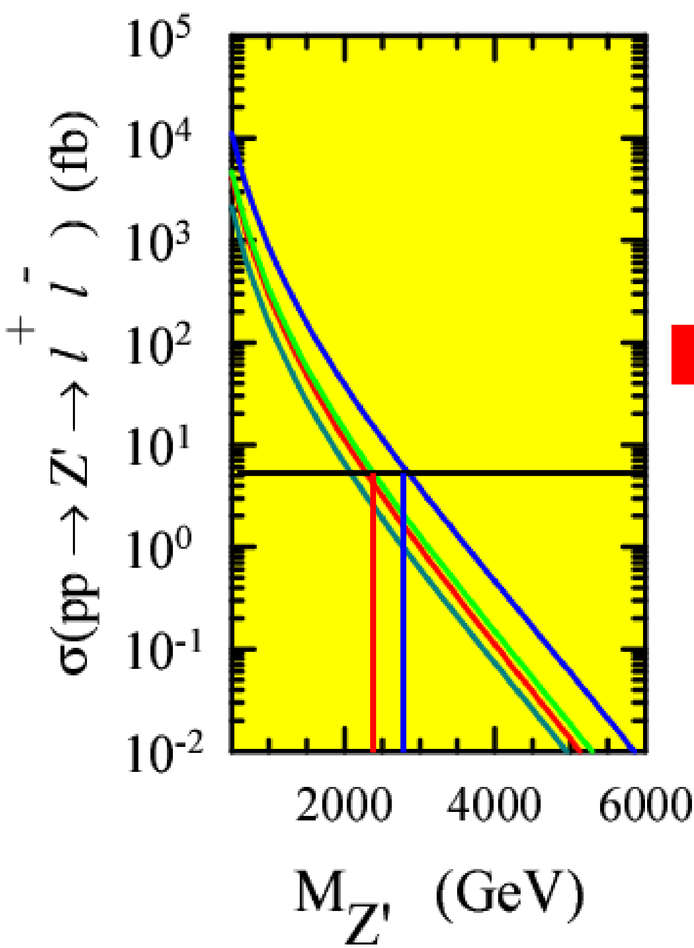
$$S_q, A_q = \left(\frac{g}{e}\right)^4 \frac{\hat{s}^2}{(\hat{s}-M^2)^2+\Gamma_{Z'}^2 M_{Z'}^2}(C_L^{f\,2} \pm C_R^{f\,2})(C_L^{q\,2} \pm C_R^{q\,2})$$

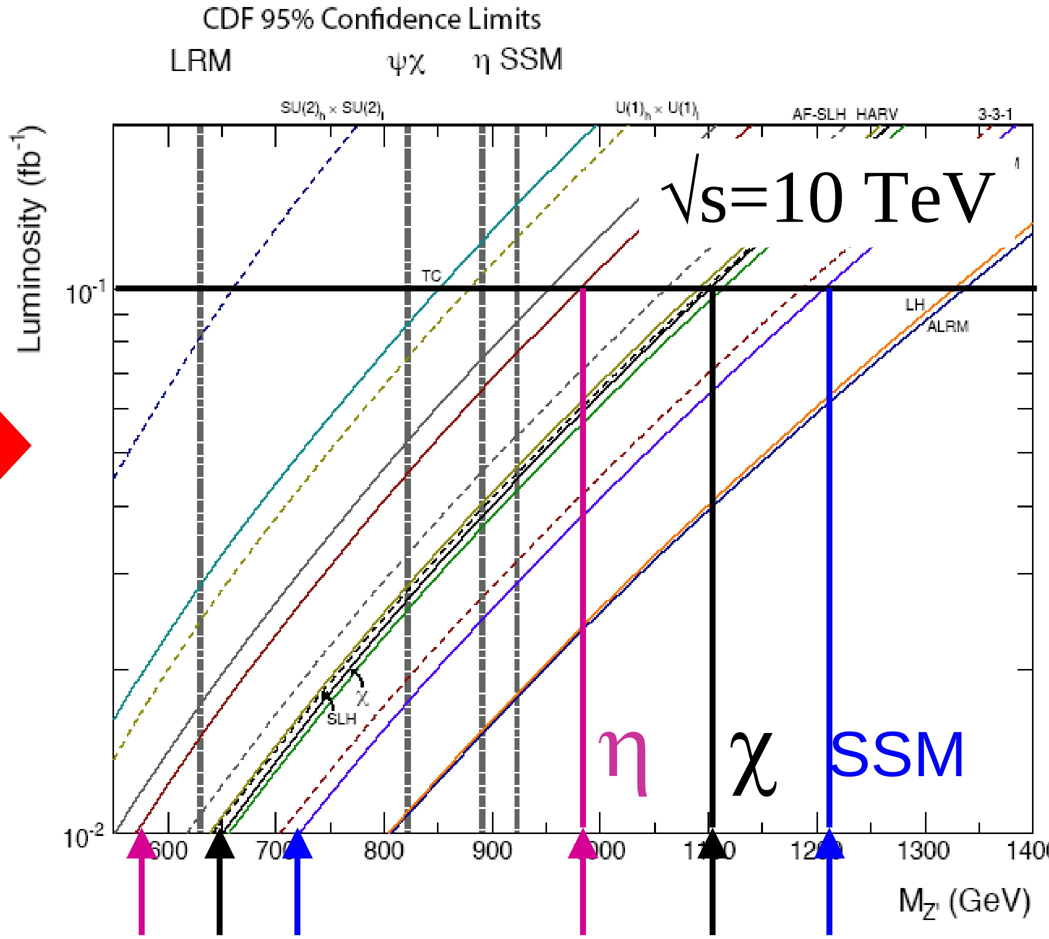
$$G_q^{\pm} = [f_{q/A}(x_A) f_{\bar{q}/B}(x_B) \pm f_{\bar{q}/A}(x_A) f_{q/B}(x_B)]$$

Discovery Limits New for Z’ Gauge Bosons

- Select 2 opposite sign high p_T isolated leptons and examine invariant mass distribution

$Z' \rightarrow \mu\mu$ production





LHC Discovers S-channel Resonance !!

What is it?

Many possibilities for an s-channel resonances:

Z', A_H, Z_H, graviton, KK excitations, …

Tools are:

- Cross sections & Widths

$$\sigma(pp \to Z' \to l^+ l^-) \simeq \sigma(pp \to Z') B(Z' \to l^+ l^0)$$

$$\sigma(pp \to Z' \to l^+ l^-)\Gamma_{Z'} \text{ is independent of B}$$

$$\Gamma(Z' \to f\bar{f}) = M_{Z'} g_{Z'}^2 ({C_L^f}^2 + {C_R^f}^2)/24\pi$$

- Angular Distributions
- Rapidity Distributions
- Couplings (decays, polarization…)
- *Etc*

Petriello & Quackenbush PRD77, 115004 (2008); arXiv:0906.4132
Carena et al, PRD70, 093009 (2004)

Z' Identification using b & t quarks

SG + T. Martin, PRL101, 151803 (2008).

The problem with quark final states is distinguishing between species and measuring Z'-quark couplings

But b and t quarks can be uniquely identified in the final state (maybe also c-quarks)

We use this property to discriminate between models

The primary issues in this analysis are:

- Identification efficiency
- Standard Model Backgrounds

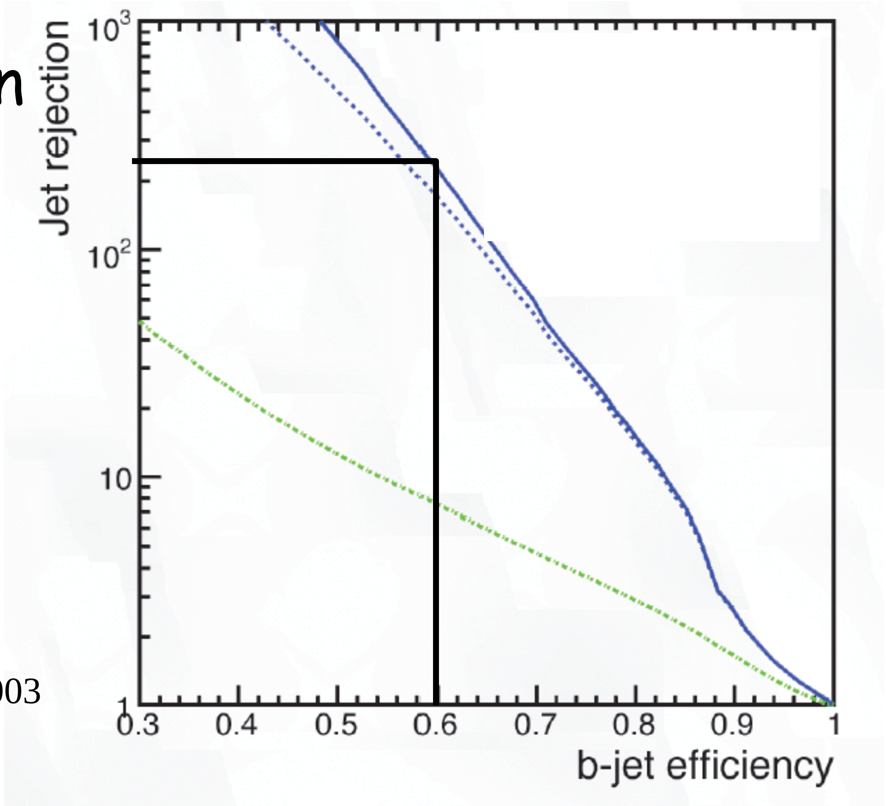
b & t identification efficiency

b-quark

- ATLAS gives ε_b=60% for high luminosity with 100   to 1 rejection against light and c-jets
- Rejection of fakes can be improved by requiring both b and b in which case we use ε_{bb}=25%

b-jet efficiency vs j rejection

ε_b=60% -> ε_{jet}~1/100



The ATLAS Collaboration, G Aad et al JINST 3 S08003

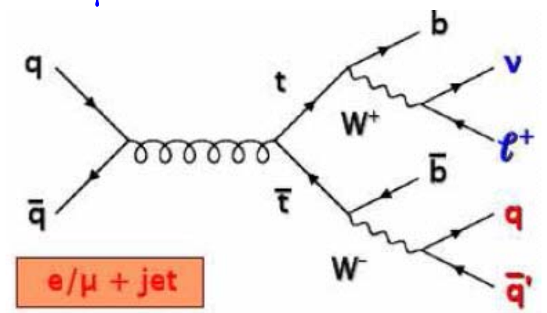
b & t identification efficiency

t-quark

- Top decays to b +W^+, with $W \to (e\nu_e, \mu\nu_\mu, \tau\nu_\tau)$ or (ud, cs)
- The single lepton + jets

$$t\bar{t} \to WWb\bar{b} \to (l\nu)(jj)(b\bar{b})$$

has a BR of ~30% and is viewed to have best signal/bgrnd



- CMS & ATLAS estimates ε_{tt}~2-5% but more recent studies give ε_{tt}~10%

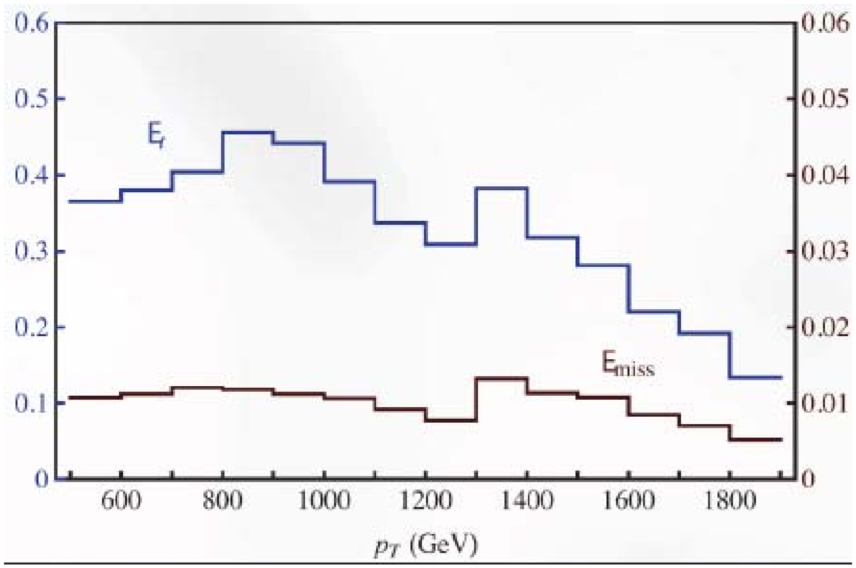
Purely hadronic modes

Kaplan, Rehermann, Schwartz & Tweedie [hep-ph/0806.0848]

See also:

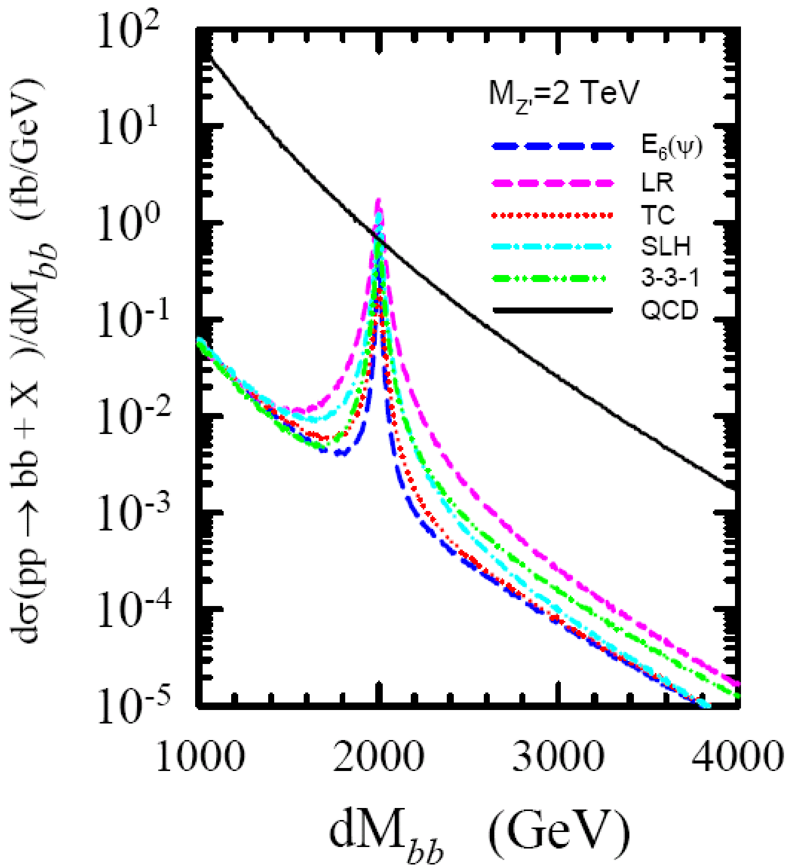
Orr and Baur [hep-ph/0707.2066]

Thaler and Wang [hep-ph/0806.0023]



If can utilize hadronic modes should increase efficiencies significantly

SM QCD Backgrounds



$$M_{Z'} = 2 \text{ TeV}$$

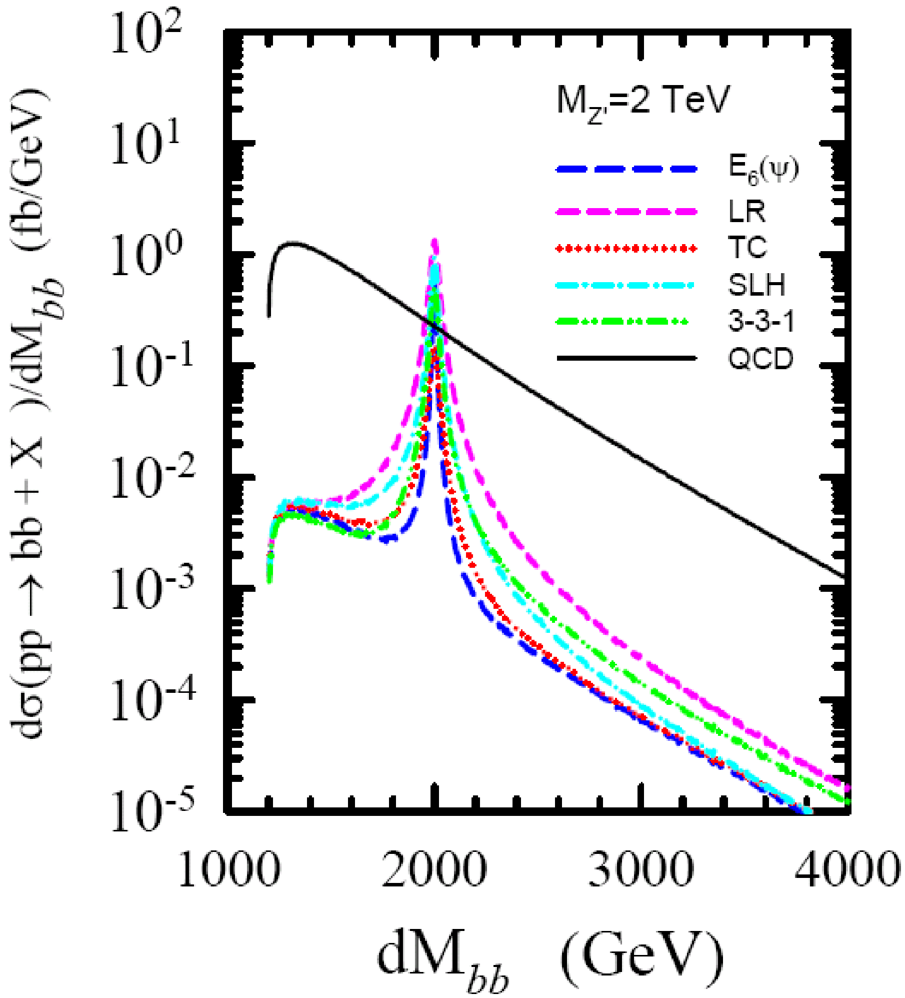
$$P_T > 50 \text{ GeV}$$

- Can reduce background by imposing a p_T cut on the reconstructed t or b
- Found

$$P_T \geq 0.3 M_{Z'}$$

reduces the background significantly

- Balance between improving signal/background vs increasing the statistical uncertainty



Can further improve S/N with

$$|M_{f\bar{f}} - M_{Z'}| \leq 2.5\,\Gamma_{Z'}$$

Other issues:

- Fakes from gluons, light quarks & c-quarks

- Non-QCD SM backgrounds

  eg: $Wb\bar{b} + jets$

  $(Wb + W\bar{b})$

  $W + jets$

Can be controlled by constraints on cluster transverse mass and invariant mass of jets

- Uncertainties in parton distribution functions

Can reduce pdf uncertainties by using ratios:

$$R_{b/\mu} \equiv \frac{\sigma(pp \to Z' \to b\bar{b})}{\sigma(pp \to Z' \to \mu^+\mu^-)} \approx \frac{BR(Z' \to b\bar{b})}{BR(Z' \to \mu^+\mu^-)} = \frac{3K_q\left(g_L^{b2} + g_R^{b2}\right)}{\left(g_L^{\mu 2} + g_R^{\mu 2}\right)}$$

$$R_{t/\mu} \equiv \frac{\sigma(pp \to Z' \to t\bar{t})}{\sigma(pp \to Z' \to \mu^+\mu^-)} \approx \frac{BR(Z' \to t\bar{t})}{BR(Z' \to \mu^+\mu^-)} = \frac{3K_q\left(g_L^{t2} + g_R^{t2}\right)}{\left(g_L^{\mu 2} + g_R^{\mu 2}\right)},$$

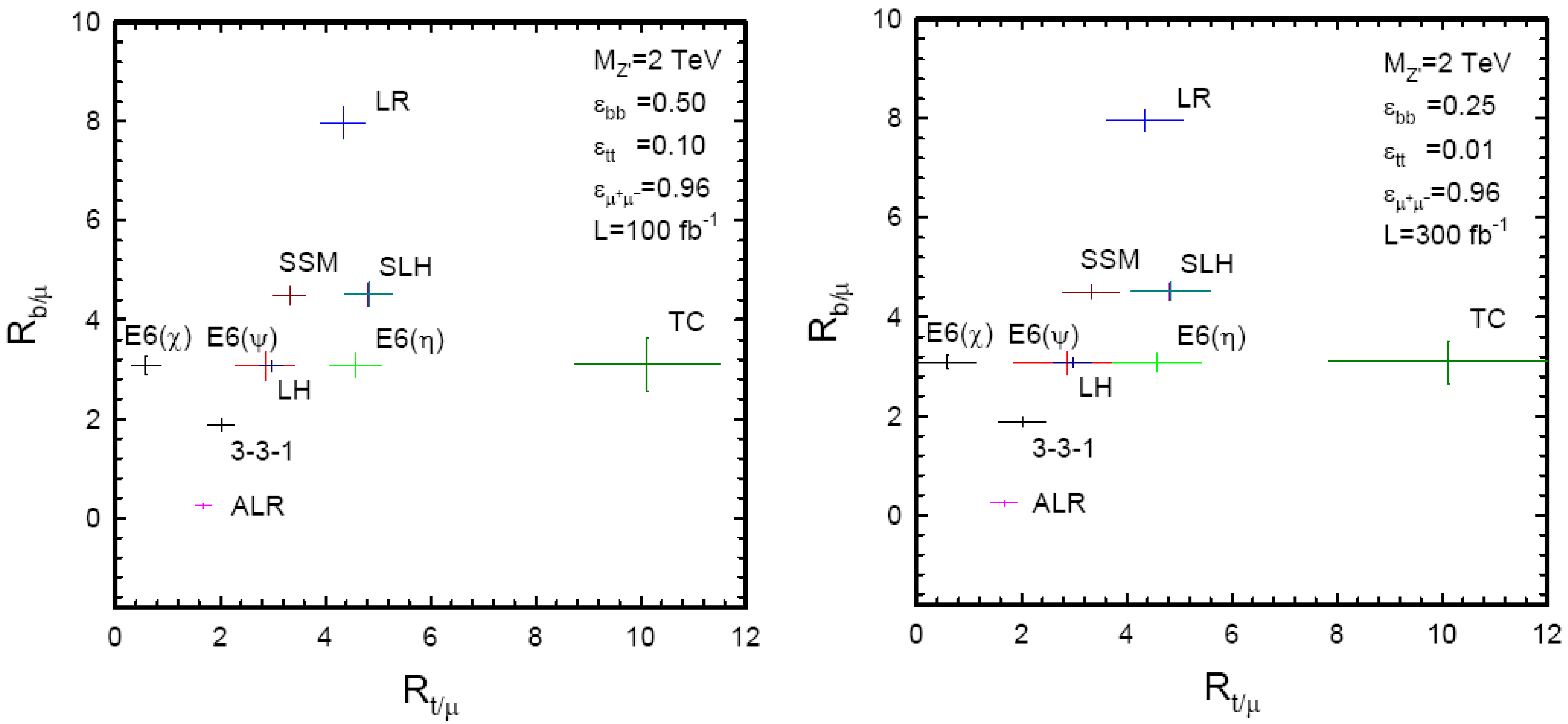
K_q depends on QCD and EW corrections

The ratios depend on model dependent couplings

Can use them to distinguish between models

Assume Z' discovered and mass and width measured

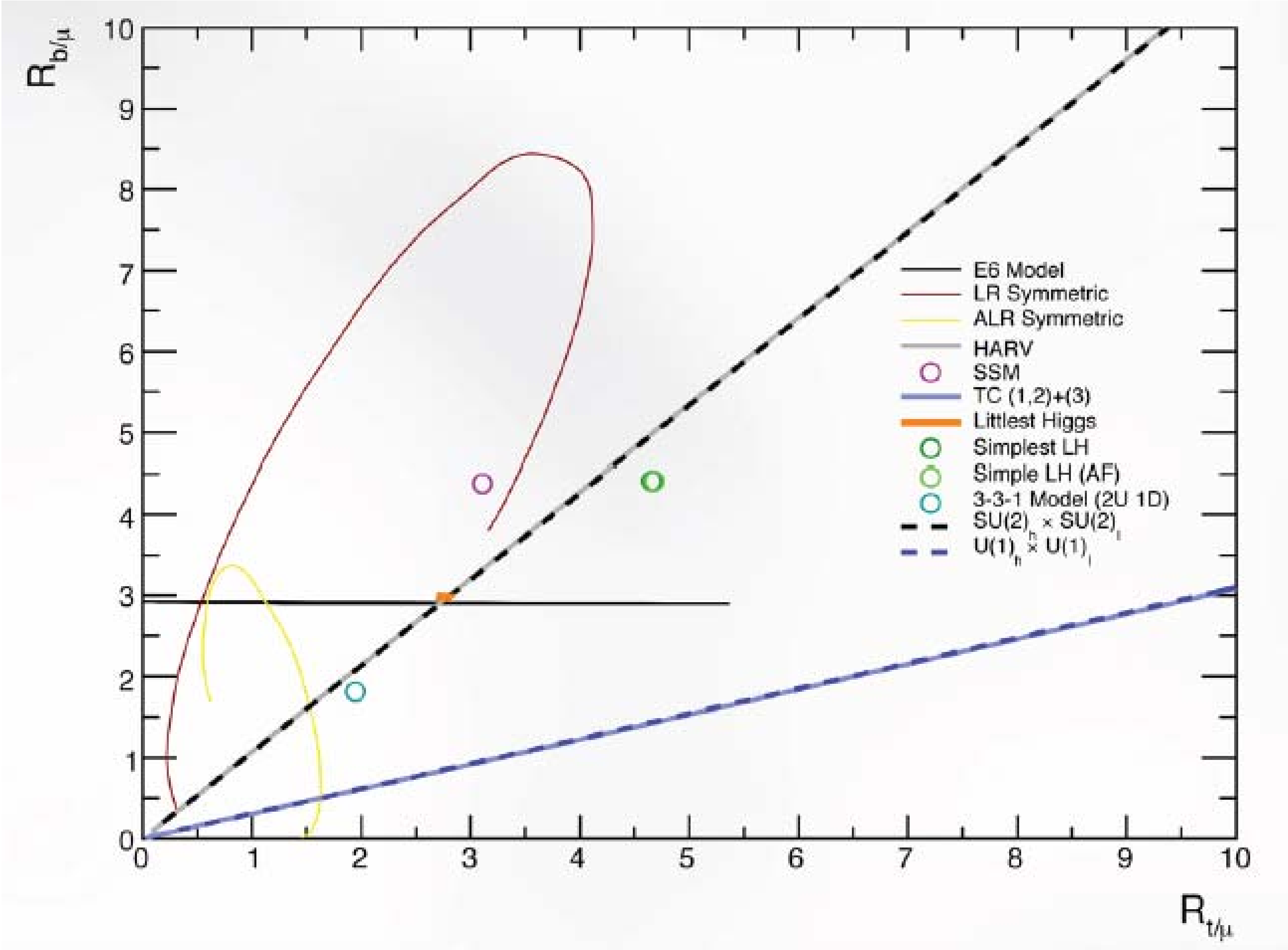
- Statistical error based on signal + background for given luminosity and ε
- Subtract SM backgrounds for predicted # of signal events



SG + T. Martin, PRL101, 151803 (2008).

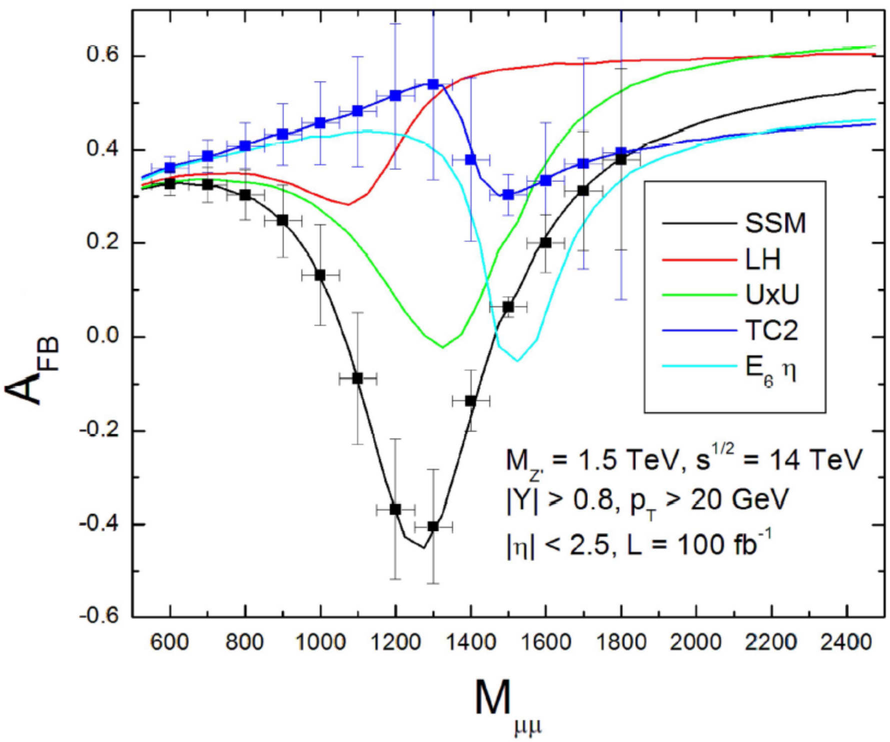
But if allow model parameters to vary have ambiguities depending on parameter

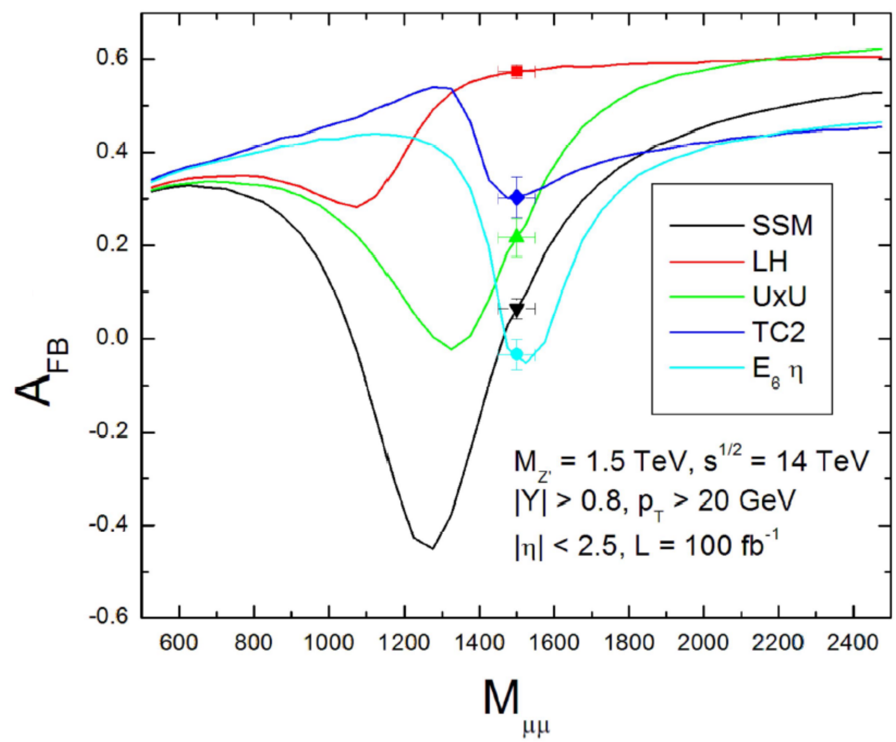
- Need additional information

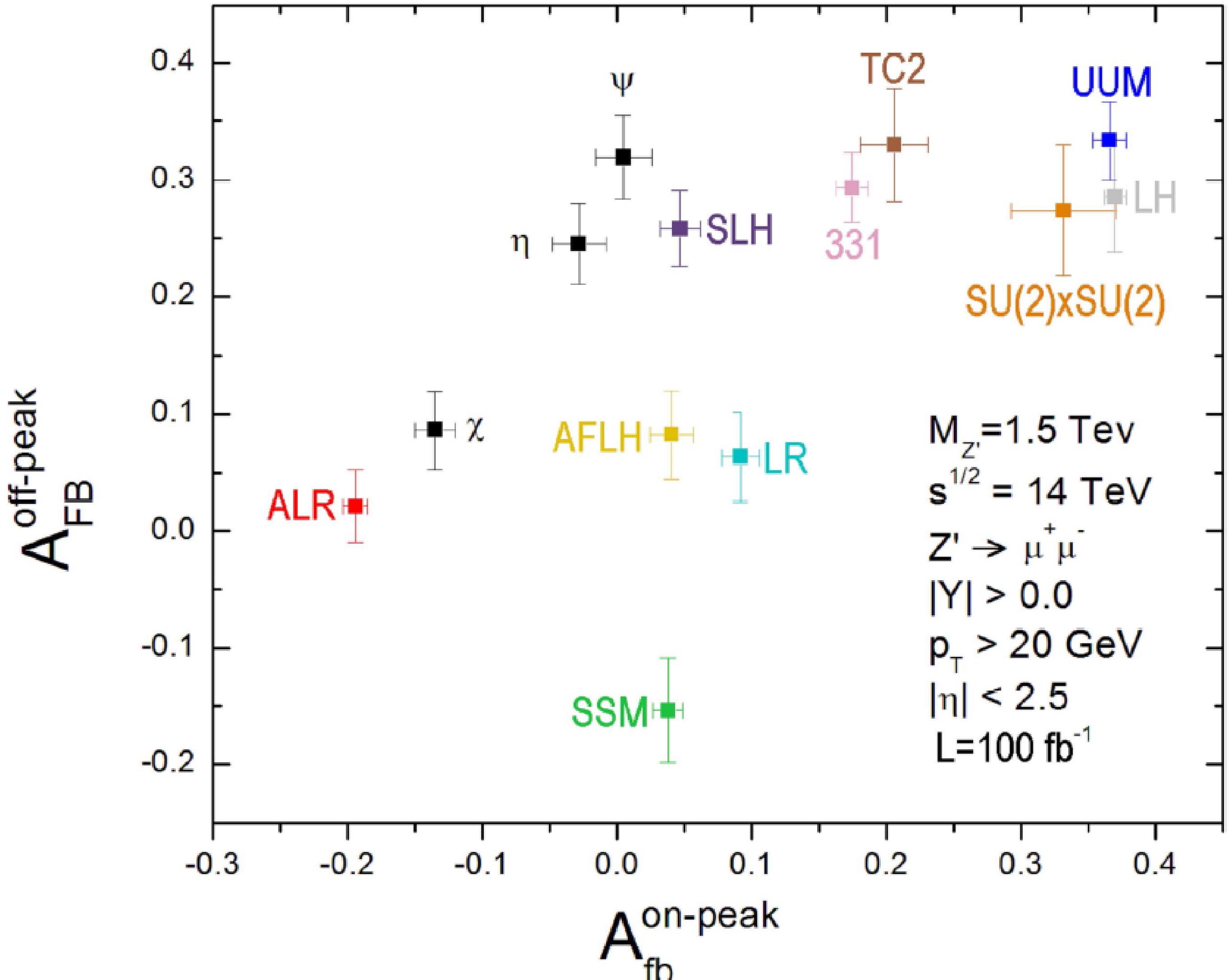


Forward Backward Asymmetry: A_{FB}

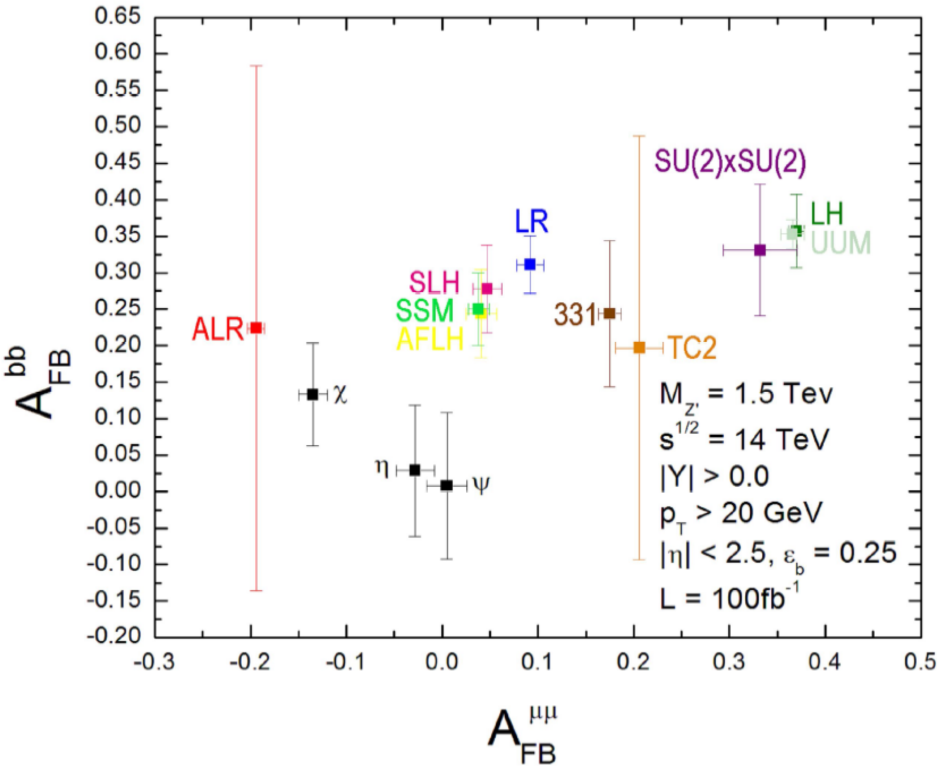
$$A_{FB} = \frac{\left[\int_{o}^{y_{max}} - \int_{-y_{max}}^{0}\right] \frac{d\sigma^-}{dy} dy}{\int_{-y_{max}}^{y_{max}} \frac{d\sigma^+}{dy} dy} \sim \left(\frac{{C_L^f}^2 - {C_R^f}^2}{{C_L^f}^2 + {C_R^f}^2} \right) \left(\frac{\sum_q G_q^- ({C_L^f}^2 - {C_R^f}^2)}{\sum_q G_q^+ ({C_L^f}^2 + {C_R^f}^2)} \right)$$



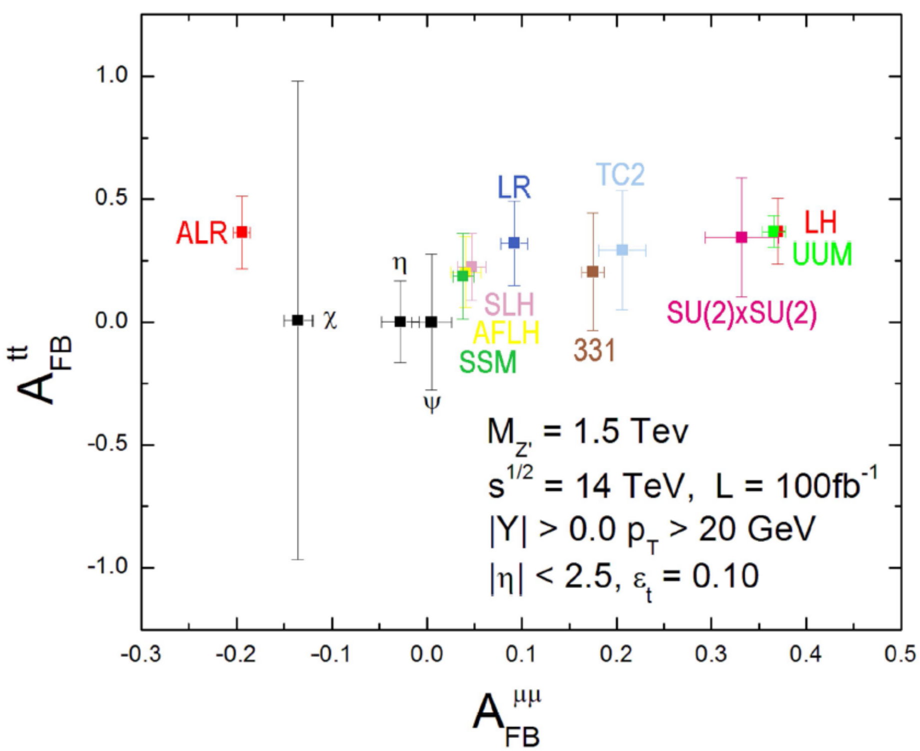




LHC can discriminate models



ALR
χ
η
ψ
SLH
SSM
AFLH
LR
331
TC2
SU(2)xSU(2)
LH
UUM
M_Z' = 1.5 Tev
s^1/2 = 14 TeV
|Y| > 0.0
p_T > 20 GeV
|η| < 2.5, ε_b = 0.25
L = 100fb^-1
A_FB^bb
A_FB^μμ



ALR
χ
η
ψ
LR
TC2
SLH
AFLH
SSM
331
SU(2)xSU(2)
LH
UUM
M_Z' = 1.5 Tev
s^1/2 = 14 TeV, L = 100fb^-1
|Y| > 0.0 p_T > 20 GeV
|η| < 2.5, ε_t = 0.10
A_FB^tt
A_FB^μμ

Summary

- s-channel resonances are predicted by many models of new physics

- One might be discovered early in the LHC program, in particular the LHC can easily find a heavy Z' like state

- The challenge will then be to figure out the underlying theory

- Numerous observables available to distinguish between models

- Showed that flavour tagging of 3rd generation quarks is can be used to distinguish models and measure individual quark couplings to Z'