Tau Custodians at the LHC

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F. del Aguila, A. Carmona, J.S. arXiv:1001.5151 and work in progress

Mechanism of EWSB: primary LHC goal

Strong EWSB is an appealing possibility

The quark sector naturally included (the top is likely quite composite)

What about the lepton sector?

- Observed pattern of lepton mixing calls for a global symmetry: tri-bimaximal mixing
- Can be easily realized in models of strong EWSB
- Lepton resonances accessible at the LHC!

Outline

- Main ingredients
  - Composite Higgs models
  - Partial compositeness
  - Custodial symmetry: fermion custodians
- A_4 symmetry and tri-bimaximal mixing
- Light new resonances: tau custodians
- New physics with taus
- Conclusions

Main Ingredients

Composite Higgs

Georgi, Kaplan, et al. 84-85

Higgs mass protected
from UV by its finite size

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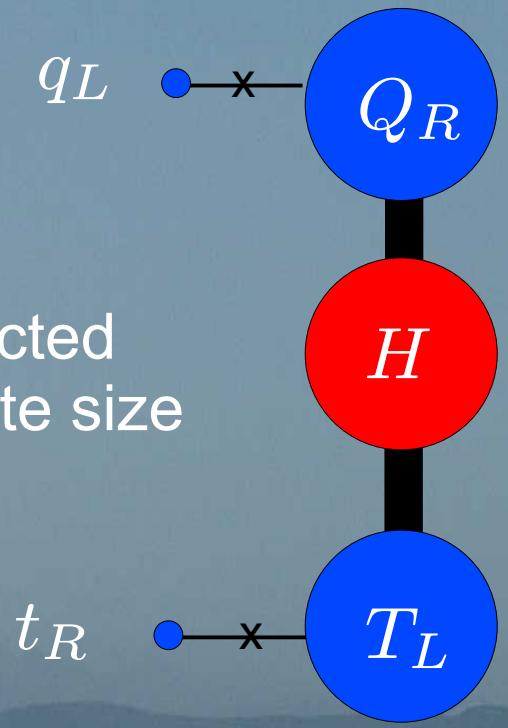


Higgs mass protected from UV by its finite size

Partial Compositeness

Kaplan 91

Contino, Kramer, Son, Sundrum 06

SM: elementary states external to the strong sector

Linear coupling: degree of compositeness

FCNC suppressed by degree of compositeness

Heavy fields more composite

Main Ingredients

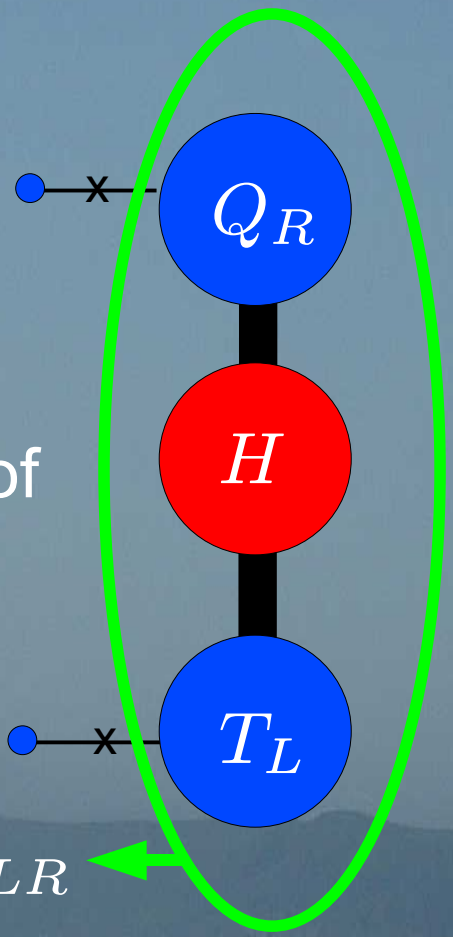
Custodial Symmetry

Sikivie et al 80; Agashe et al 03

$\Delta T = 0$ (tree level)

Custodial protection of $Z\bar{\psi}\psi$ coupling

Agashe, Contino, Da Rold, Pomarol 06



$SU(2)_L \times SU(2)_R \times P_{LR}$

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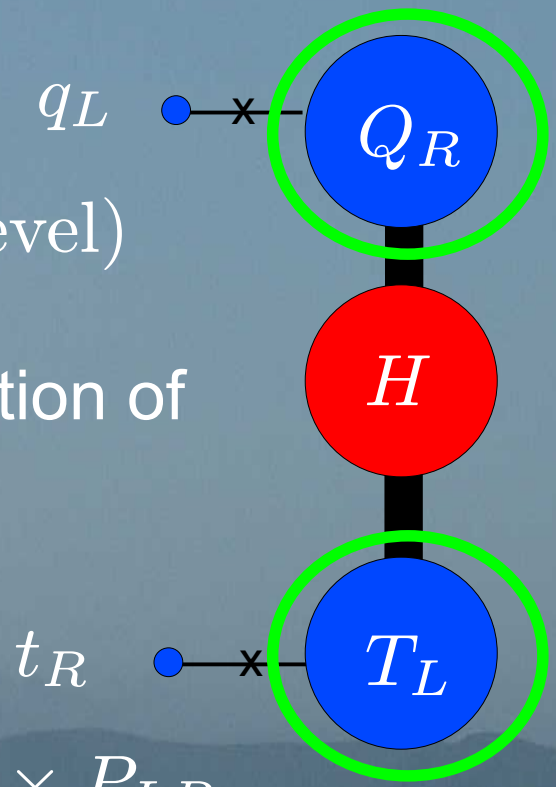


$SU(2)_L \times SU(2)_R \times P_{LR}$

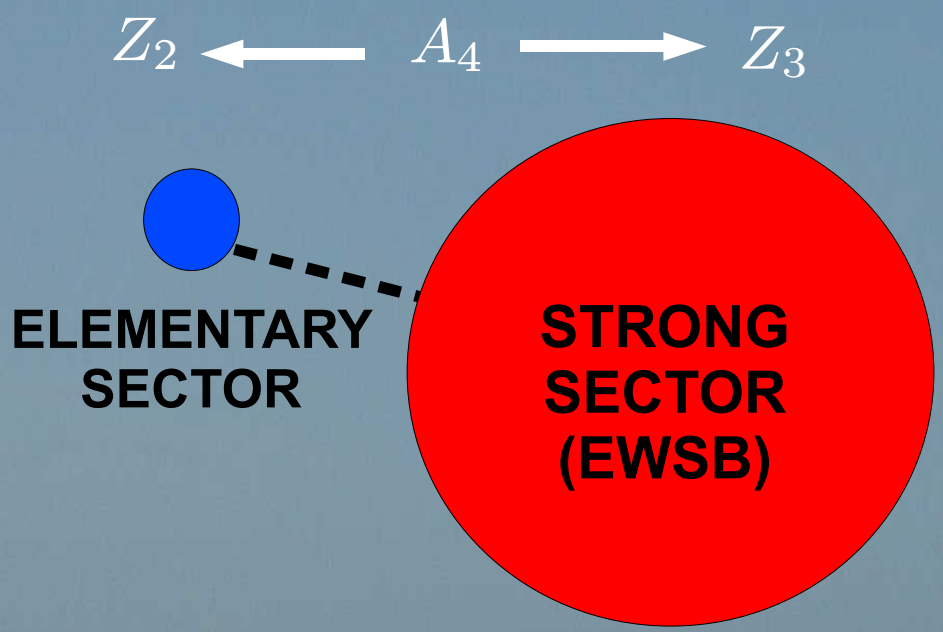
Fermion Custodians

Fermion custodians: partners under custodial symmetry of composites mixing with elementary fields.

- Naturally light and strongly coupled for very composite fields

A4 in Composite Higgs Models: lepton custodians

Aguila, Carmona, Santiago '10



- Charged lepton Yukawas: diagonal and hierarchical
- Neutrino Yukawas: proportional to the identity
- The only source of mixing is the (elementary sector) neutrino Majorana mass
  - See-saw $m \sim \mathrm{TeV}^2/M_P$
  - Tri-bimaximal mixing

A4 in Composite Higgs Models: lepton custodians

Aguila, Carmona, Santiago '10

Corrections to tri-bimaximal mixing and flavor universality generated from higher dimensional operators $\propto \frac{v}{\Lambda}$ — **A4 breaking**, **Cut-off scale**

$\mu \to e\gamma \propto \frac{v^3}{\Lambda^3}$ requires $\frac{v}{\Lambda} \lesssim 0.01 - 0.1$

$m_\tau \propto \frac{v}{\Lambda}$ suppressed $\Rightarrow \tau$ very composite

Tau custodians: new light lepton resonances with strong coupling to the tau

Lepton Custodians

Aguila, Carmona, Santiago '10

Tau custodians: new light leptonic resonances that decay only through taus

Tau couplings protected (custodial symmetry)

Explicit realization: two degenerate doublets with hypercharges -1/2 and -3/2

$T^1, T^2 \quad (Q = -1)$

$N \quad (Q = 0)$

$Y \quad (Q = -2)$

$T^1 \to Z\tau \qquad N \to W^+\tau$

$T^2 \to H\tau \qquad Y \to W^-\tau$

(100%)

Lepton Custodians

Aguila, Carmona, Santiago '10

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$$T^1, T^2 \quad (Q = -1)$$
$$N \quad (Q = 0)$$
$$Y \quad (Q = -2)$$

$$M_{T^1} = M_N = M_Y$$

$$M_{T^2} \gtrsim M_{T^1}$$

New Physics with Taus

Aguila, Carmona, Santiago in progress

EW production (relatively low xsection)

But very light resonances (and high multiplicities -many custodians) allowed

Multi-lepton final state: negligible backgrounds

- Pair production
- Require one leptonic Z
- Require leptonic decay of the two taus

New Physics with Taus

Aguila, Carmona, Santiago in progress

Signature $pp \to l^+ l^- l'^+ l''^- jj \not{E}_T \qquad l, l', l'' = e, \mu$

Crucial feature:

Plehn, Rainwater, Zeppenfeld '99

- Taus can be fully reconstructed
  - They are hard ➡ their decay products are very collimated: we assume full collimation to reconstruct tau momentum
- Require no further missing energy

New Physics with Taus

Aguila, Carmona, Santiago in progress

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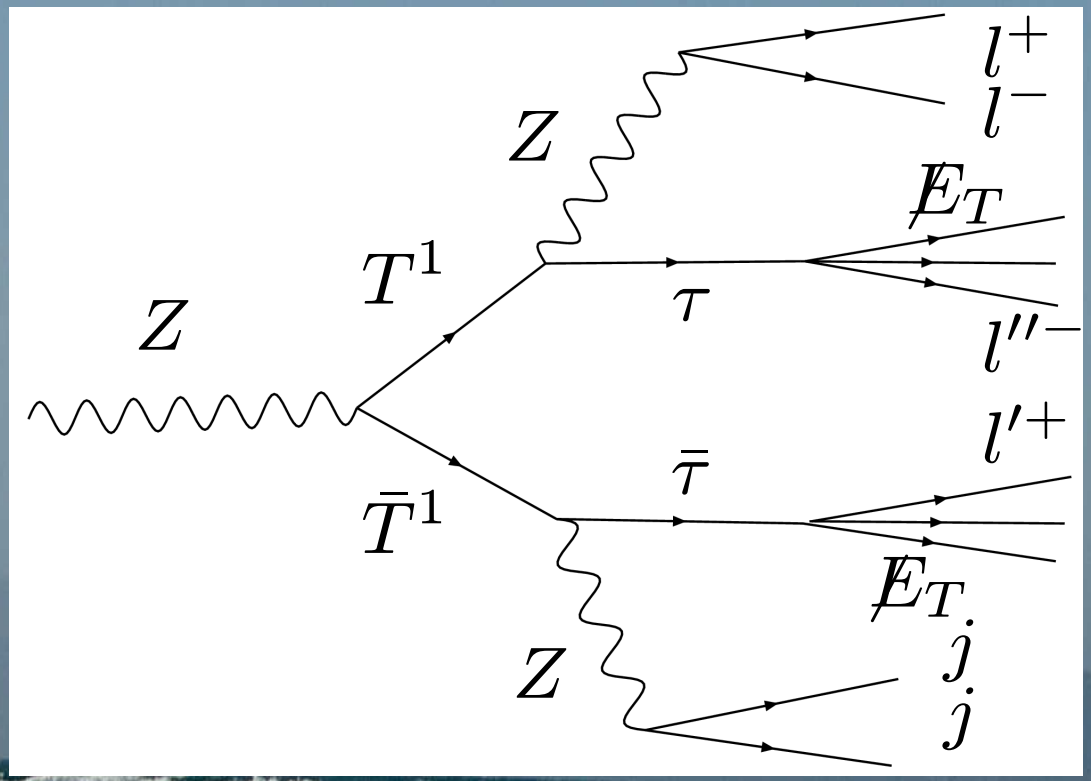

Very collimated

Very collimated

New Physics with Taus

Aguila, Carmona, Santiago in progress

Signature $pp \to l^+ l^- l'^+ l''^- jj \not{E}_T \qquad l, l', l'' = e, \mu$

Main backgrounds:

Z t t+ jets (n=2)

Z b b+ jets (n=2)

t t + jets (n=2)

ZZ+ jets (n=2)

ZW+ jets (n=2)

ALPGEN V2.13

MG/ME V4

MLM matching

PYTHIA6

PGS4

New Physics with Taus

Aguila, Carmona, Santiago in progress

PRELIMINARY

Cuts:

$p_T(l) \geq 10$ GeV

$l^+l^-l'^+l''^-jj \not{E}_T$

$p_T(j), \not{E}_T \geq 20$ GeV

$|\eta_l| \leq 2.5, |\eta_j| \leq 5, \Delta R_{jj,lj} \geq 0.5$

$|M_{l^+l^-} - M_Z| \leq 10$ GeV

$\cos(\phi_{l'^+l''^-}) \geq -0.95$

50 GeV $\leq M_{jj} \leq 150$ GeV

Reconstruct taus assuming collinearity

New Physics with Taus

Aguila, Carmona, Santiago in progress

Reconstruct taus assuming collinearity:

$$p_i^{l'\pm} = x^{\pm} p_i^{\tau\pm}, \quad \bar{p}_i^{\pm} = (1 - x^{\pm}) p_i^{\tau\pm}$$

neutrino momenta

$$0 \leq x^{\pm} \leq 1$$

Fixed by momentum conservation

$$p_i^{\tau\pm} = \frac{p_i^{l'\pm}}{x^{\pm}} \qquad p_0^{\tau\pm} = \sqrt{m_\tau^2 + \sum_{i=x,y,z} (p_i^{\tau\pm})^2}$$

New Physics with Taus

Aguila, Carmona, Santiago in progress

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Reconstruct taus assuming collinearity $\quad 0 \leq x^{\pm} \leq 1$

$|M_{L^1} - M_{L^2}| \leq 100$ GeV

$|M_{\tau Z} - M_{L^{\text{test}}}| \leq 50$ GeV

New Physics with Taus

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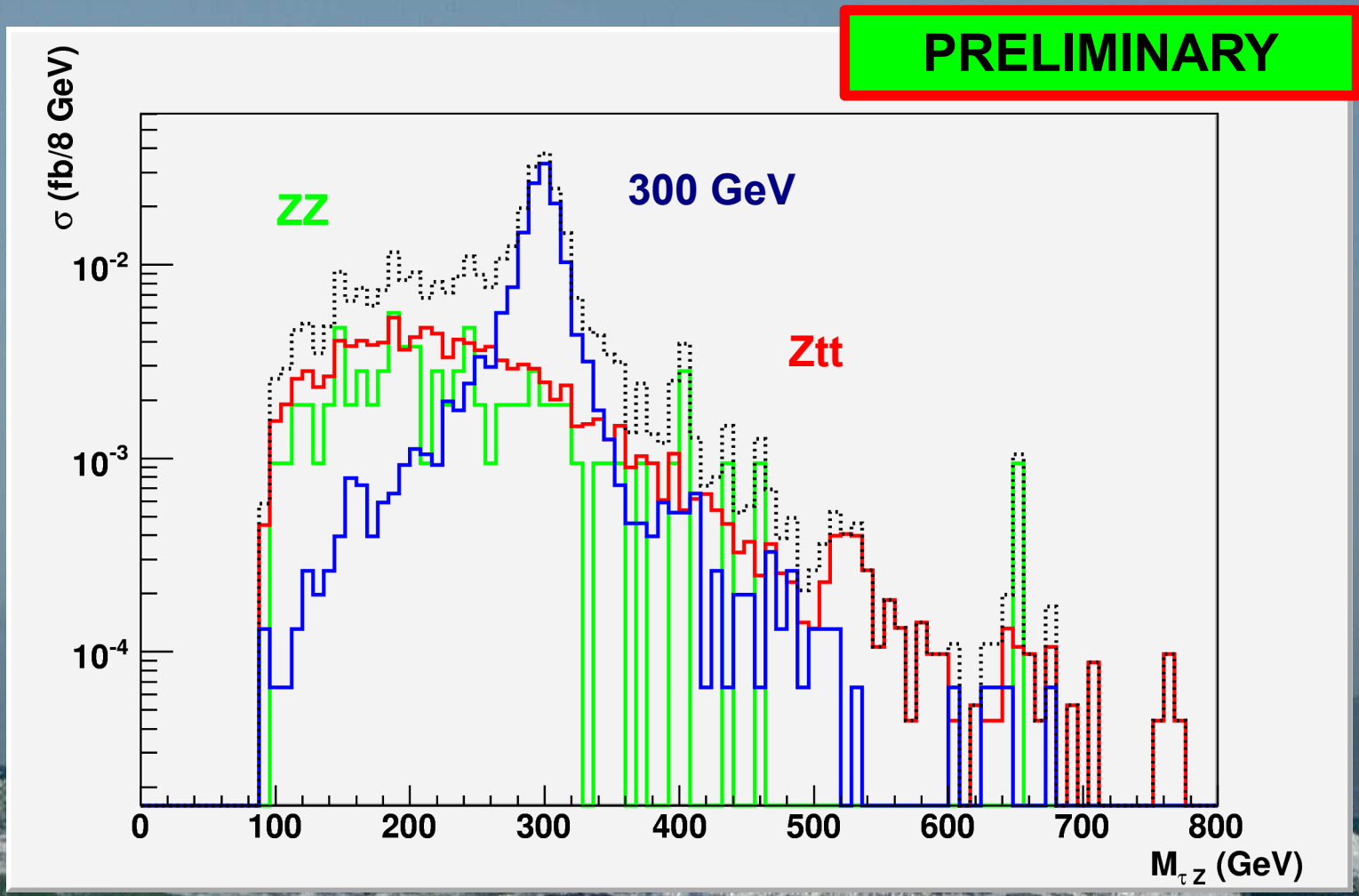
Mass reconstruction

$LHC \quad 14\mathrm{TeV}$



New Physics with Taus

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Analysis: $LHC \quad 14\text{TeV}$

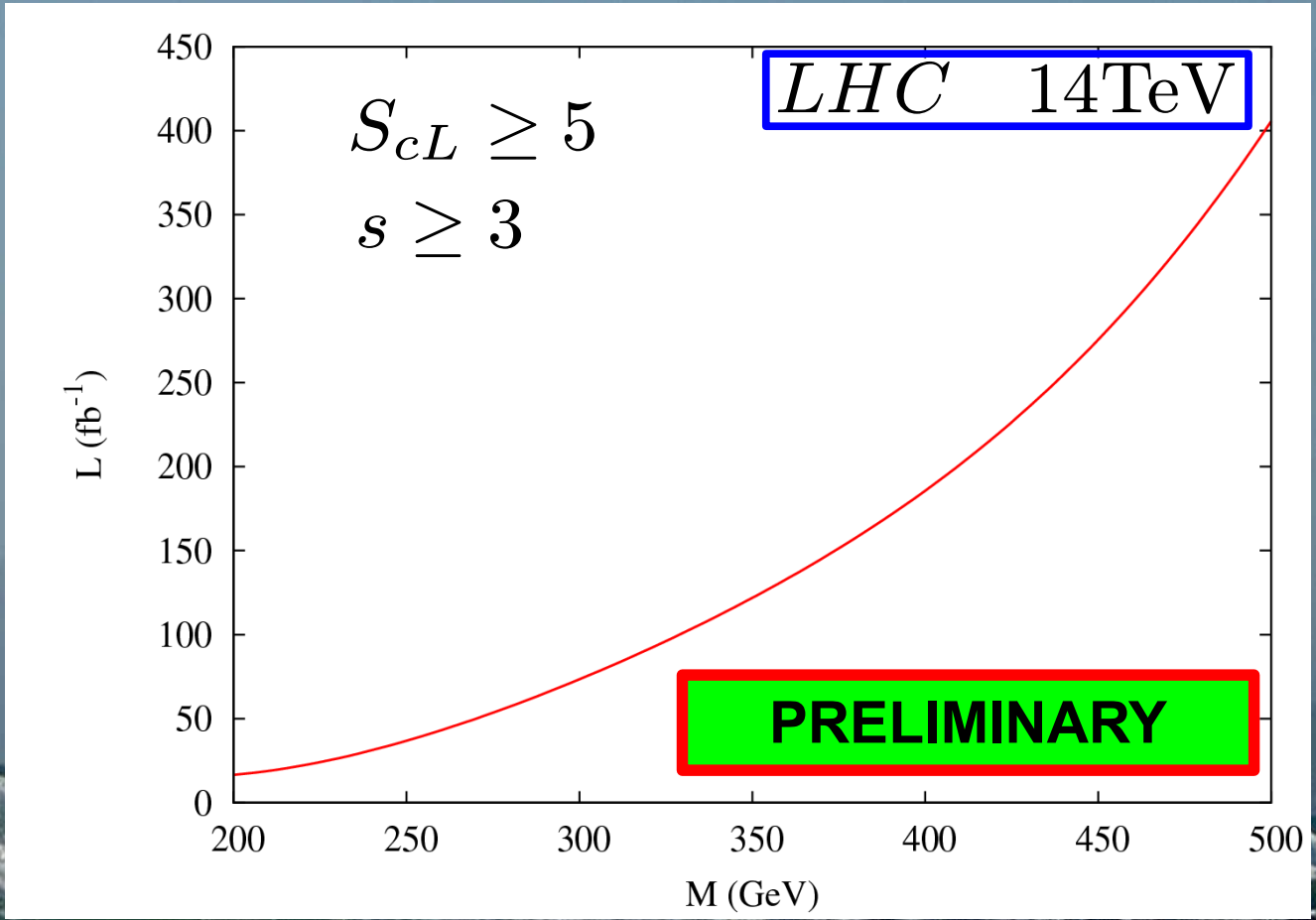
PRELIMINARY

$(\sigma$ in fb$^{-1})$	$M = 200\ GeV$	$Zt\bar{t}$	ZZ
basic	0.85	0.58	0.33
$M_{l^+l^-}$	0.68 (0.81)	0.49 (0.85)	0.30 (0.90)
M_{jj}	0.49 (0.72)	0.17 (0.34)	0.11 (0.36)
τ reconstr.	0.42 (0.86)	0.043 (0.26)	0.033 (0.31)
$\lvert M_{L^1} - M_{L^2}\rvert$	0.42 (0.99)	0.030 (0.69)	0.025 (0.77)
$M_{\tau Z}$	0.39 (0.95)	0.012 (0.41)	0.016 (0.63)

New Physics with Taus

Aguila, Carmona, Santiago in progress

Discovery luminosity $S_{cL} \equiv \sqrt{2\left[(s+b)\ln\left(1-\frac{s}{b}\right)-s\right]}$



Conclusions

Composite Higgs models are a natural candidate for a theory of EWSB

Custodial symmetry allows for new very light fermionic resonances with large couplings to SM fermions: custodians

A4 models naturally predict tau custodians

New physics in multi-lepton final states (with taus): strong background reduction