

Multi-lepton final states in search of New Physics at the LHC
IST (Lisbon) Thursday March 25, 2010

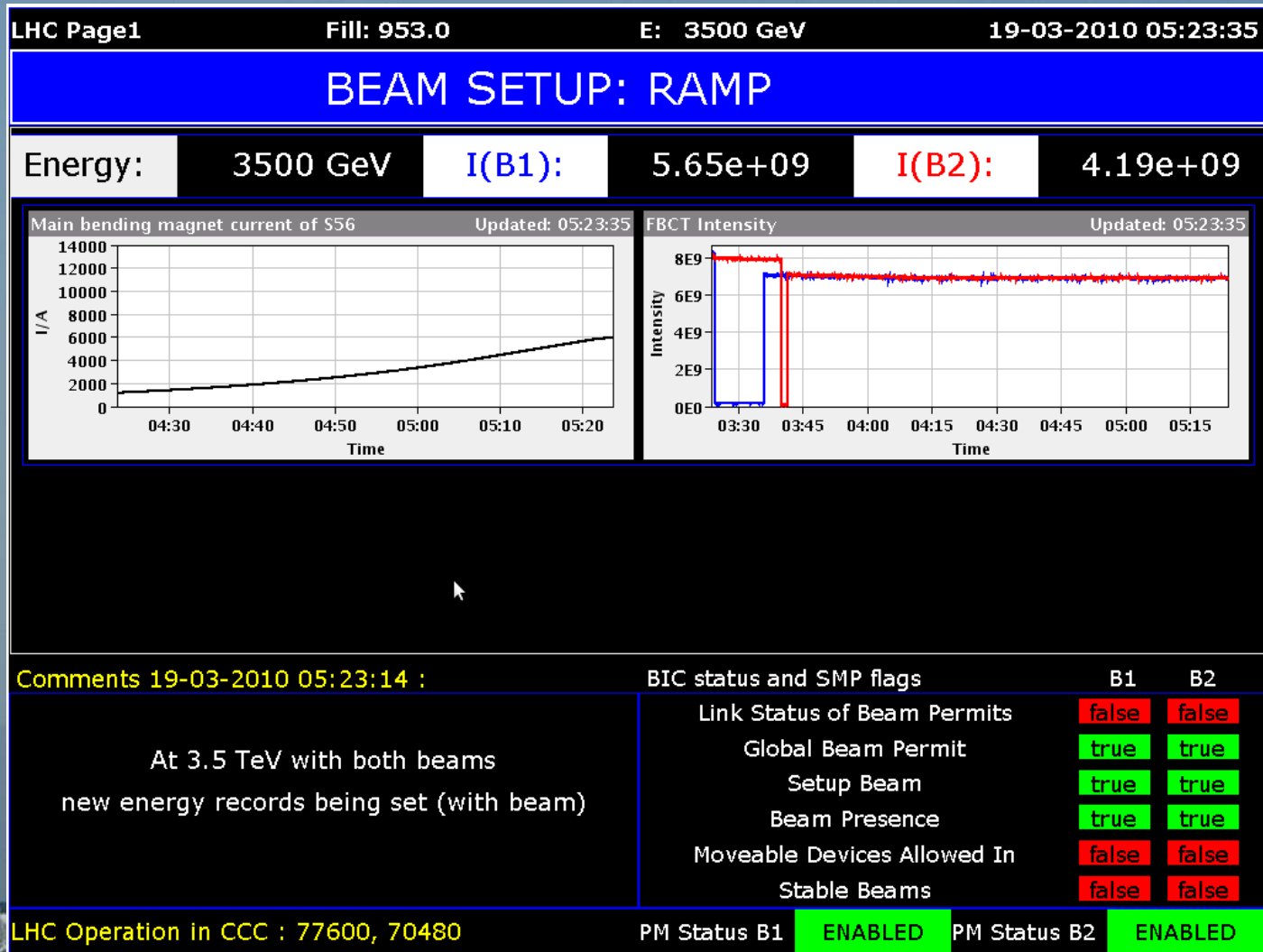
Multi-lepton signals in Composite Higgs Models



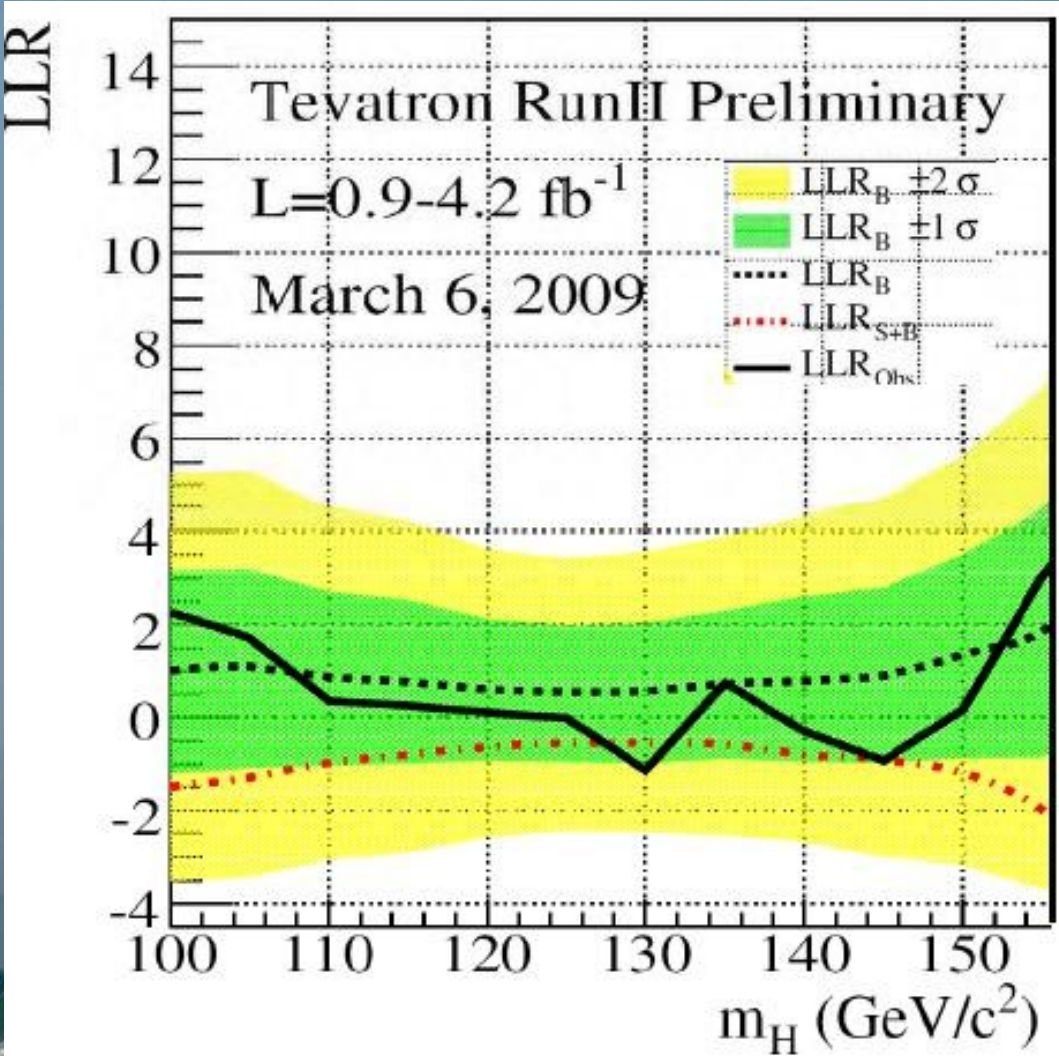
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Universidad de Granada

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

The LHC is finally ready!



The race for the Higgs is heating up!



The race for the Higgs is heating up!

... But which Higgs?

- The SM Higgs is not natural

$$\delta m_H^2 \sim \Lambda^2$$

The Higgs wants to be as heavy as the heaviest physical scale

- A natural alternative is a composite Higgs:

$$\delta m_H^2 \sim f^2 \sim \text{TeV}^2$$

Finite size: insensitive to UV

- Can show up in multi-lepton final states



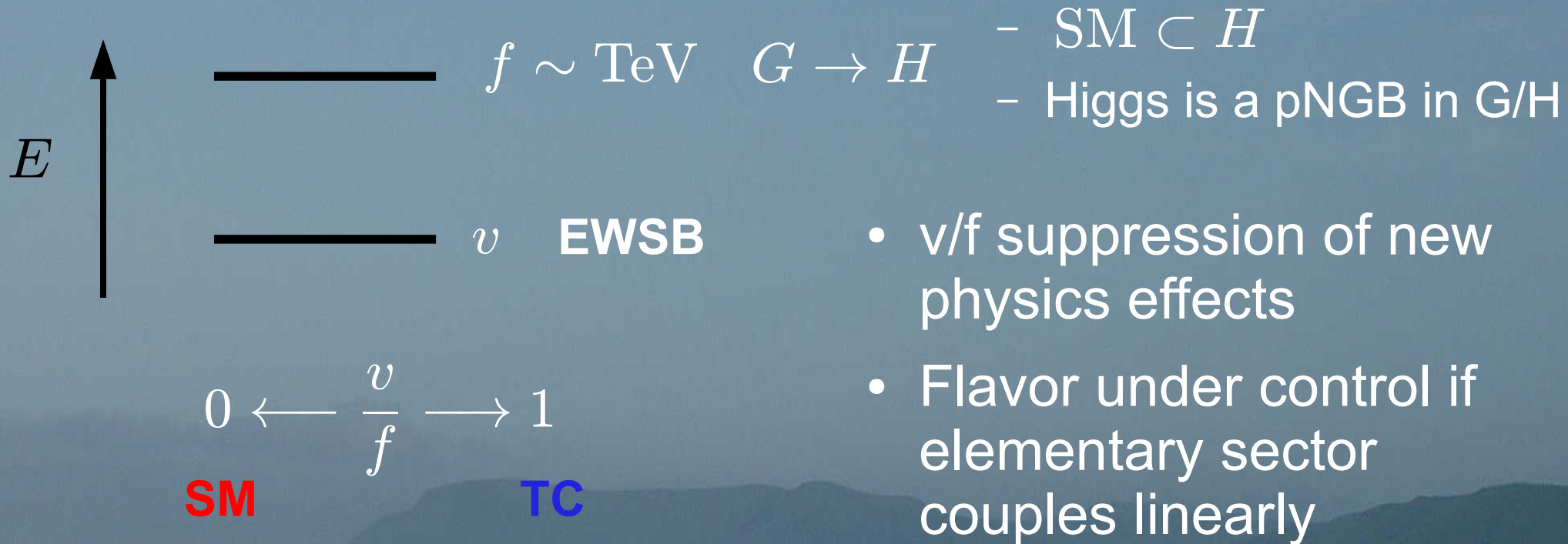
Outline

- Composite Higgs models
- Partial compositeness
- Necessary ingredients: Custodial symmetry
- Light new resonances: fermion custodians
 - Quark custodians
 - Lepton custodians:
 - Neutrinos, A_4 symmetry and light lepton custodians
 - New physics at the LHC with taus
- Conclusions



Composite Higgs Models

- Two scale symmetry breaking: **Georgi, Kaplan, et al. 84-85**



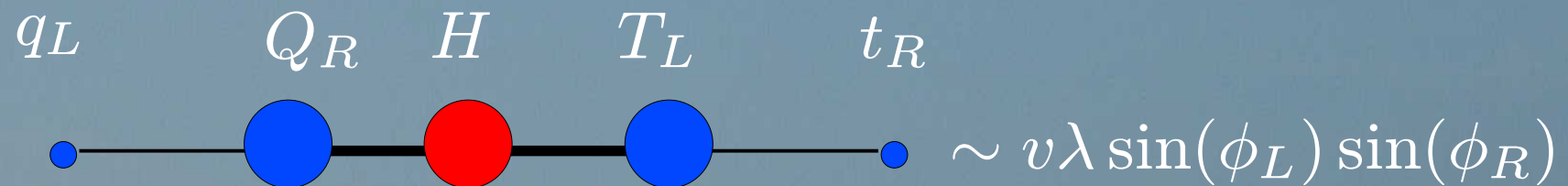
Kaplan 91

Composite Higgs Models

Kaplan 91

- Partial Compositeness: Contino, Kramer, Son, Sundrum 06

- SM: elementary states external to the strong sector
- Linear coupling: degree of compositeness



- Natural realization of flavor
- Heavier fields are more composite (stronger interaction to new physics)

Necessary ingredients

- New strong sector accessible at the LHC?

- Custodial symmetry: $\Delta T = 0$ (tree level)

Agashe,
Delgado, May,
Sundrum 03

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

Agashe, Contino, Da
Rold, Pomarol 06

$$SU(2) \rightarrow SU(2)_L \times SU(2)_R$$

$$P_{LR}$$



Necessary ingredients

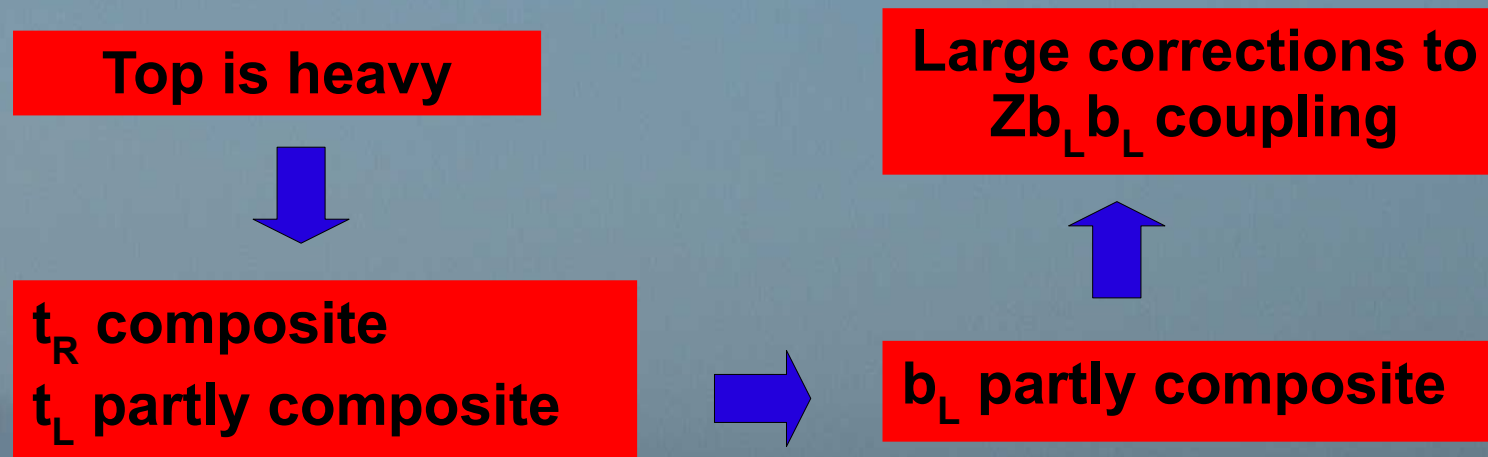
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Also protects flavor: **Albrecht et al 08-09**

Necessary ingredients

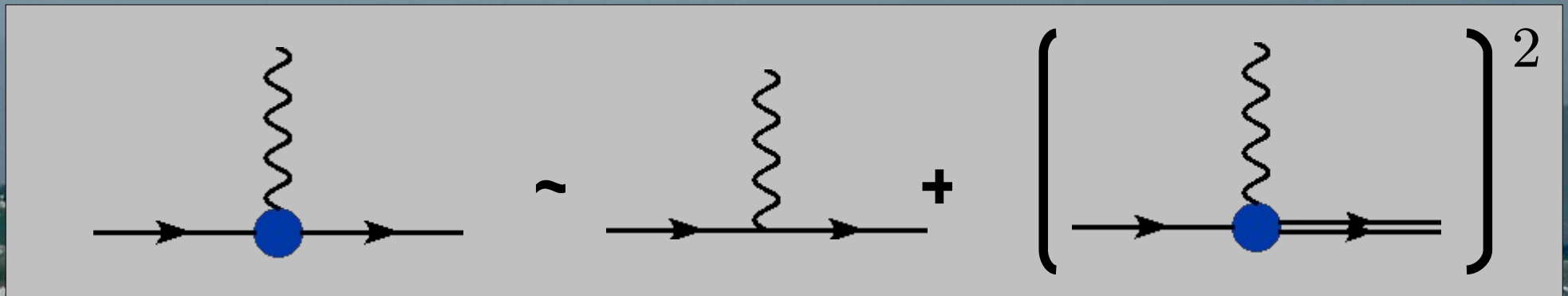
- New strong sector accessible at the LHC?
 - Custodial symmetry: $\Delta T = 0$ (tree level)
 - Custodial protection of $Z\bar{\psi}\psi$ coupling



- Very light new fermions allowed!!!

Common lore

Anastasiou, Furlan, Santiago 09

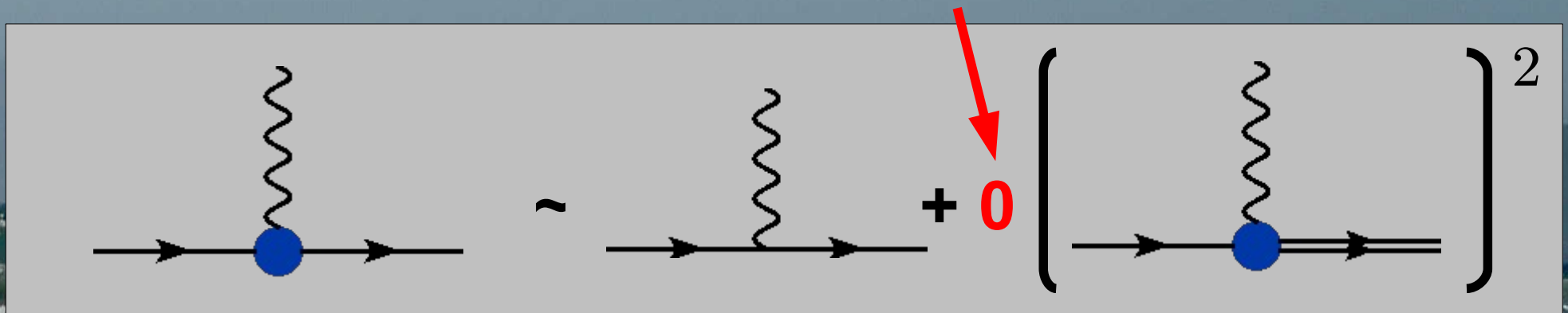


Necessary ingredients

- New strong sector accessible at the LHC?
 - Custodial symmetry: $\Delta T = 0$ (tree level)
 - Custodial protection of $Z\bar{\psi}\psi$ coupling
- ↓
- Very light new fermions allowed!!!

With custodial protection

Anastasiou, Furlan, Santiago 09



Fermion Custodians

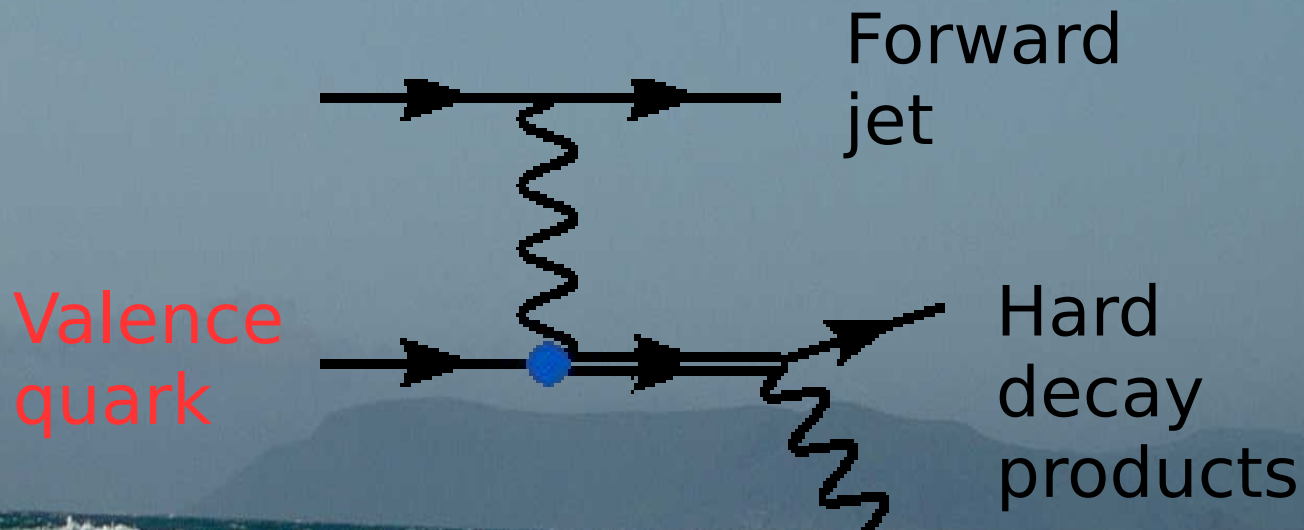
- Cancellations due to extra fields (custodial partners of the composite with SM quantum numbers)
- **Custodians** of very composite SM fields are light and couple strongly (in a custodially protected way)
- Natural scenario: new light vector-like quarks with a large coupling to the top **See JAAS' talk**

Contino, Servant 08
Aguilar-Saavedra 09
Mrazek, Wulzer 09

Quark Custodians

Atre, Carena, Han, Santiago 09

- Also possible for light generations
- Large (unconstrained) coupling to valence quarks
- Distinctive kinematics (single production)

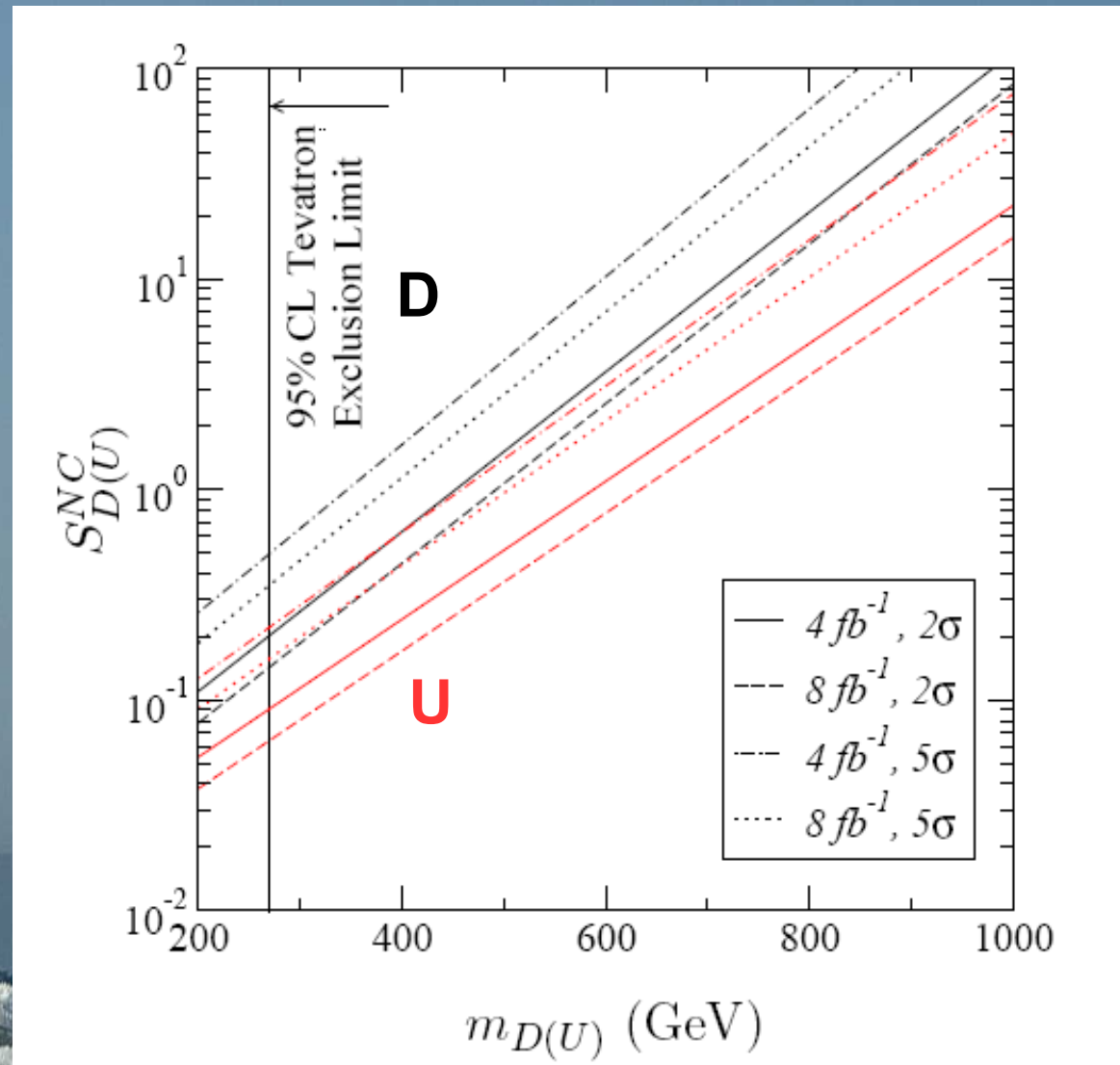


Quark Custodians

Atre, Carena, Han, Santiago 09

- Tevatron analysis
 - NC channel
- LHC analysis in progress

Atre, Azuelos, Carena, Han, Ozkan, Santiago, Unel




Lepton Custodians

Aguila, Carmona, Santiago '10

- All **analyses** (of composite Higgs models) so far have **focused on the quark sector**
- Small neutrino masses and large mixing angles can be naturally realized in composite Higgs models
- An A_4 symmetry predicts **tri-bimaximal** mixing, correct scale of **neutrino masses** and **very light new physics compatible with electroweak and flavor constraints**

Lepton Custodians

Aguila, Carmona, Santiago '10

- Corrections to TBM mixing and flavor universality generated from higher dimensional operators $\propto \frac{v}{\Lambda}$  **A4 breaking UV scale**
- $\mu \rightarrow e\gamma \propto \frac{v^3}{\Lambda^3}$ requires $\frac{v}{\Lambda} \lesssim 0.01 - 0.1$
- $m_\tau \propto \frac{v}{\Lambda}$ suppressed $\Rightarrow \tau$ **very composite**

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 $-3/2$

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

$$N \quad (Q = 0)$$

$$Y \quad (Q = -2)$$

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

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

Lepton Custodians

Aguila, Carmona, Santiago '10

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

$$N \quad (Q = 0)$$

$$Y \quad (Q = -2)$$

$$T^1 \rightarrow Z\tau \quad N \rightarrow W^+\tau$$

$$T^2 \rightarrow H\tau \quad Y \rightarrow W^-\tau$$

(100%)

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



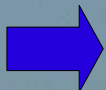
New Physics with Taus

Aguila, Carmona, Santiago in progress

- Signature $pp \rightarrow l^+ l^- l'^+ l''^- jj \cancel{E}_T$ $l, l', l'' = e, \mu$

- Crucial feature:

Plehn, Rainwater, Zeppenfeld '99

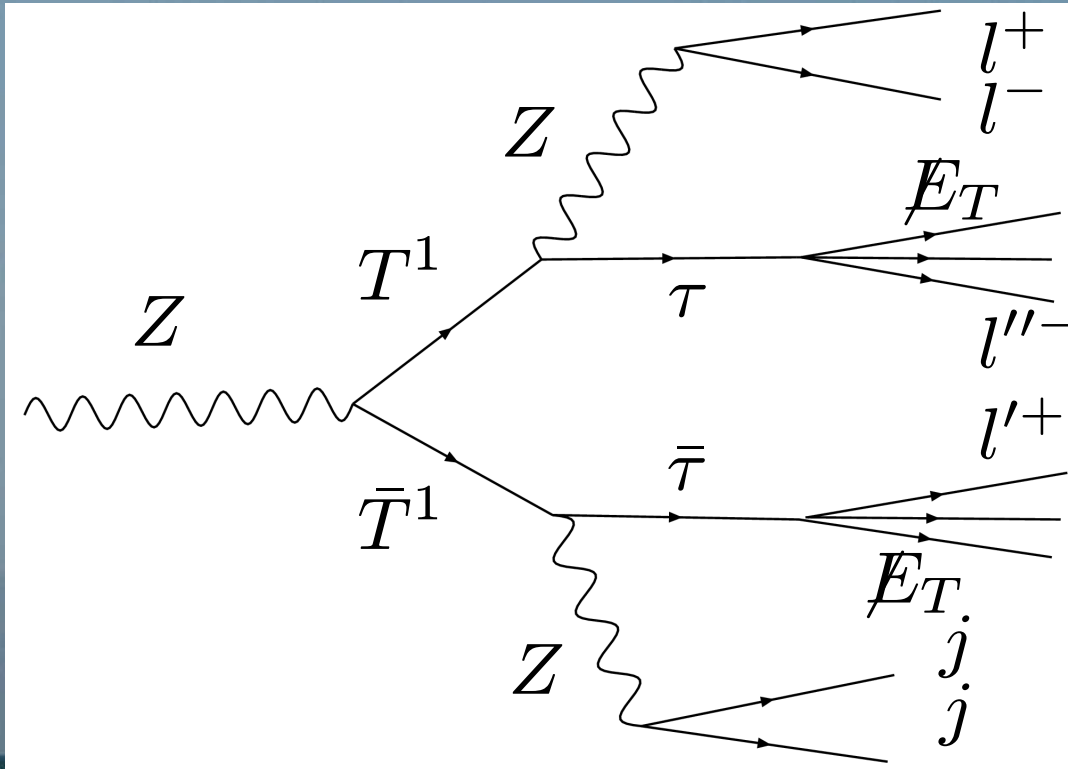
- Taus can be fully reconstructed
 - They are hard  their decay products are very collimated: we assume full collimation to reconstruct tau momentum
- Require no further missing energy



New Physics with Taus

Aguila, Carmona, Santiago in progress

- Signature $pp \rightarrow l^+ l^- l'^+ l''^- jj \cancel{E}_T$ $l, l', l'' = e, \mu$



Very collimated

Very collimated

New Physics with Taus

Aguila, Carmona, Santiago in progress

- Signature $pp \rightarrow l^+ l^- l'^+ l''^- jj \cancel{E}_T$ $l, l', l'' = e, \mu$
- Main backgrounds: (incomplete list)

- Z t t+ jets (n=2)

- Z b b+ jets (n=2)

- ZZ+ jets (n=2)

- ZW+ jets (n=2)



ALPGEN V2.13

MADGRAPH V 4.4.32

MLM matching

Hadronization + showering + ISR + FSR: PYTHIA

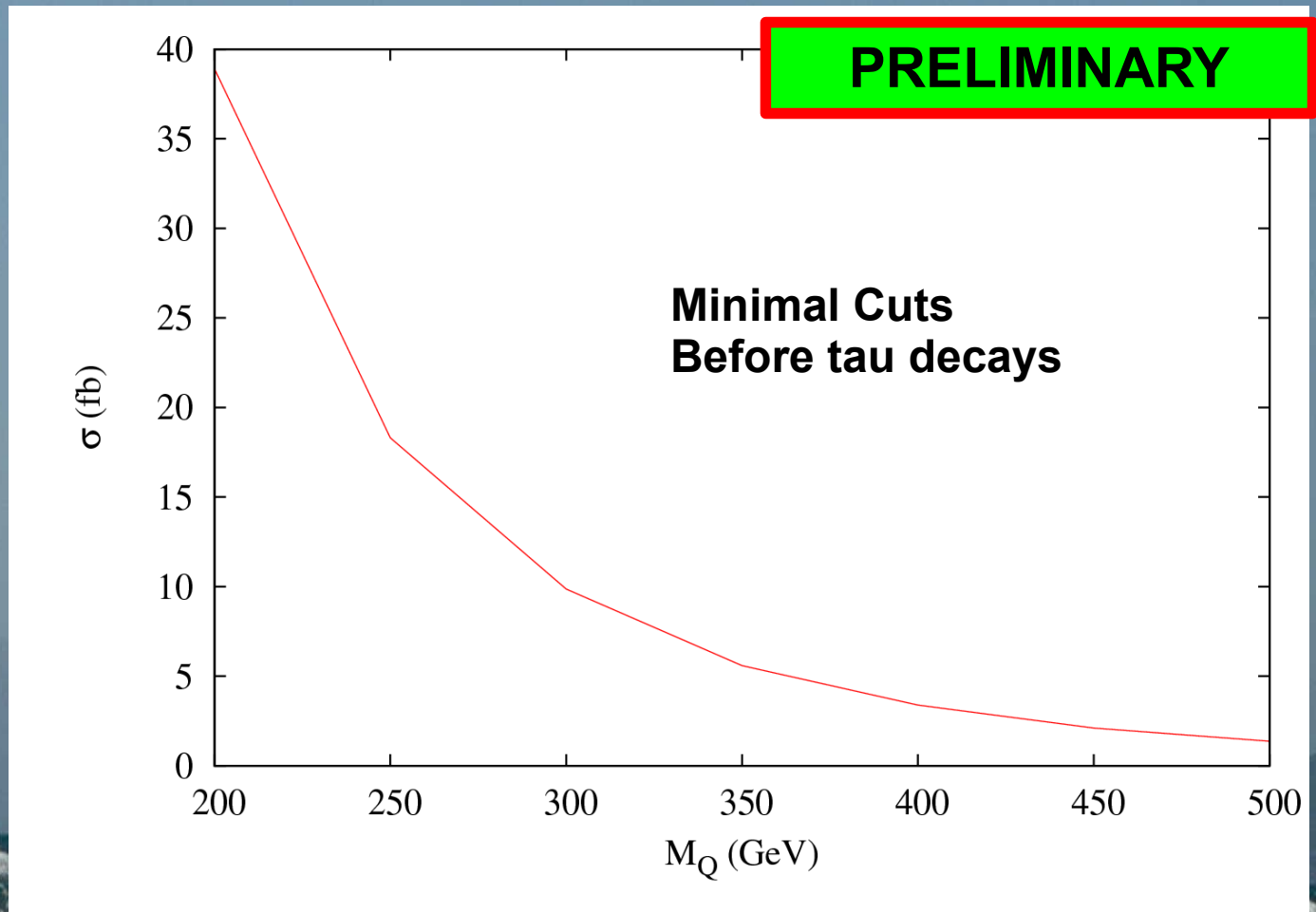
Fast detector simulation: PGS

New Physics with Taus

Aguila, Carmona, Santiago in progress

- Production x section

LHC 14TeV



New Physics with Taus

Aguila, Carmona, Santiago in progress

PRELIMINARY

- Cuts: $p_T(l) \geq 10 \text{ GeV}$
 - $l^+l^-l'^+l''^-jj \cancel{E}_T$ $p_T(j), \cancel{E}_T \geq 20 \text{ GeV}$
 $|\eta_l| \leq 2.5, |\eta_j| \leq 5, \Delta R_{jj,lj} \geq 0.7$
 - $|M_{l^+l^-} - M_Z| \leq 5 \text{ GeV}$ $\cos(\phi_{l'^+l''^-}) \geq -0.95$
 - $50 \text{ GeV} \leq M_{jj} \leq 200 \text{ GeV}$
 - Reconstruct taus assuming collinearity
 - $|M_{L^1} - M_{L^2}| \leq 100 \text{ GeV}$
 - $|M_{\tau Z} - M_{L^{\text{test}}}| \leq 50 \text{ GeV}$

New Physics with Taus

Aguila, Carmona, Santiago in progress

- Cuts:

LHC 14TeV

PRELIMINARY

Cuts	Signal (300 GeV) fb^{-1}	ztt fb^{-1}	zz fb^{-1}
basic	0.31	0.41	0.29
M_{l+l-}	0.25	0.34	0.27
M_{jj}	0.18	0.17	0.12
$ M_{L^1} - M_{L^2} $	0.16	0.12	0.08
$M_{\tau Z}$	0.13	0.03	0.02

$$\mathcal{L}_{5\sigma} \approx 77 \text{fb}^{-1}$$

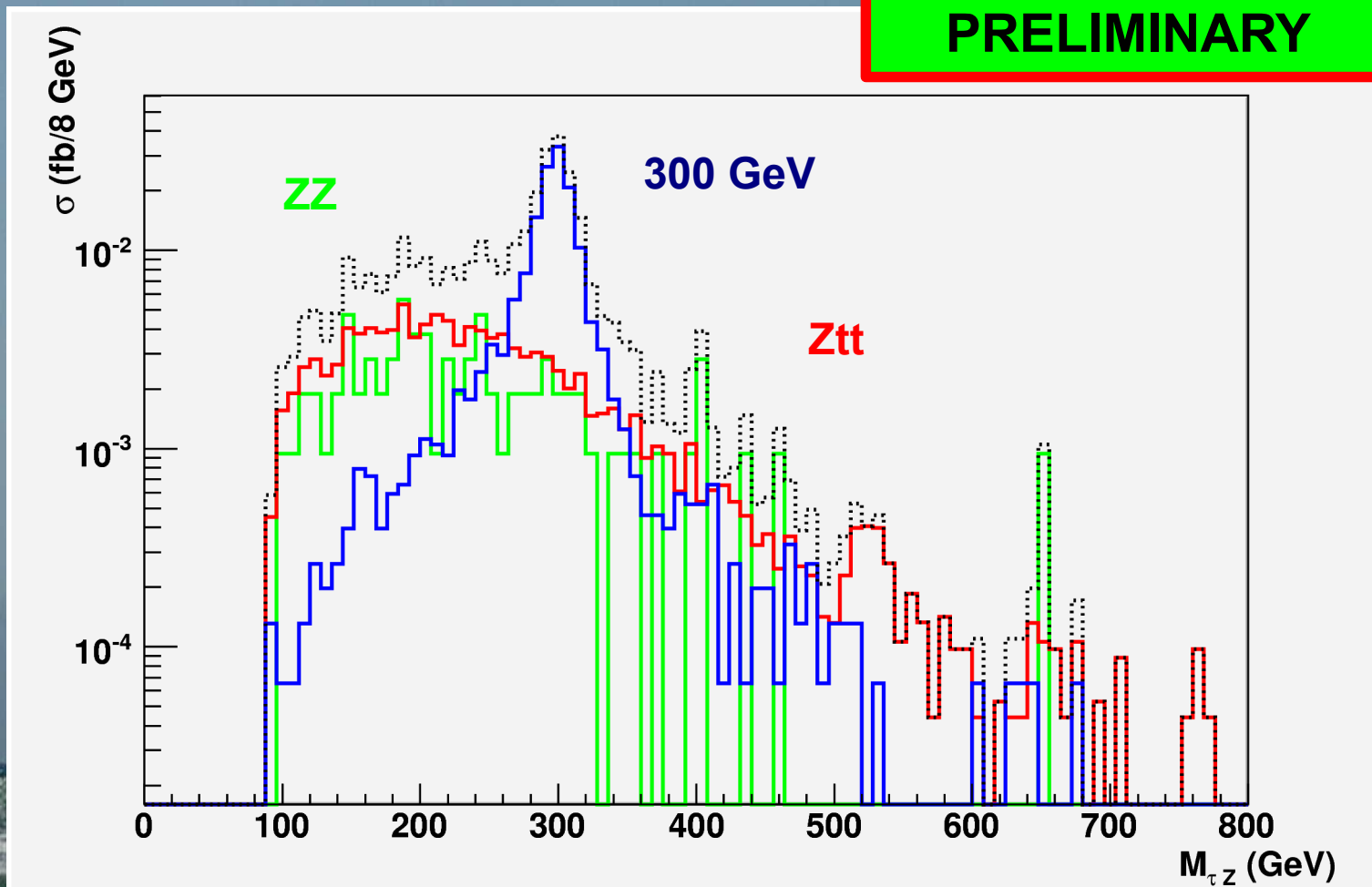
New Physics with Taus

Aguila, Carmona, Santiago in progress

- Mass reconstruction

LHC 14TeV

PRELIMINARY

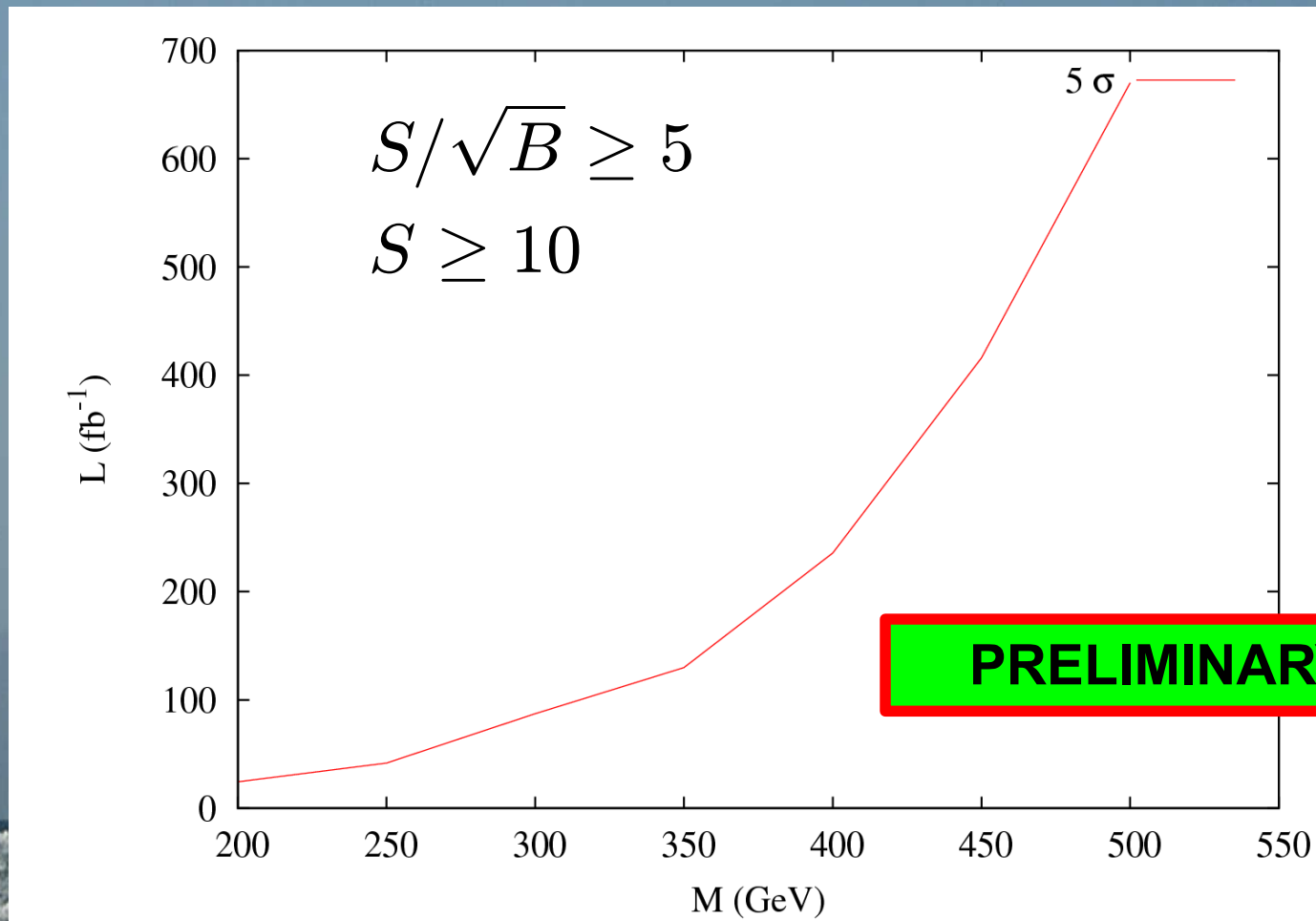


New Physics with Taus

Aguila, Carmona, Santiago in progress

- Discovery luminosity

LHC 14TeV



New Physics with Taus

Aguila, Carmona, Santiago in progress

- Work in progress:
 - Cuts must be optimized
 - Early run analysis in progress (very light resonances with large couplings allowed)
 - 1 fb^{-1} @ $3.5+3.5 \text{ TeV}$
 - Comparison with single production

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



Back-up slides



Quark Custodians

Atre, Carena, Han, Santiago 09

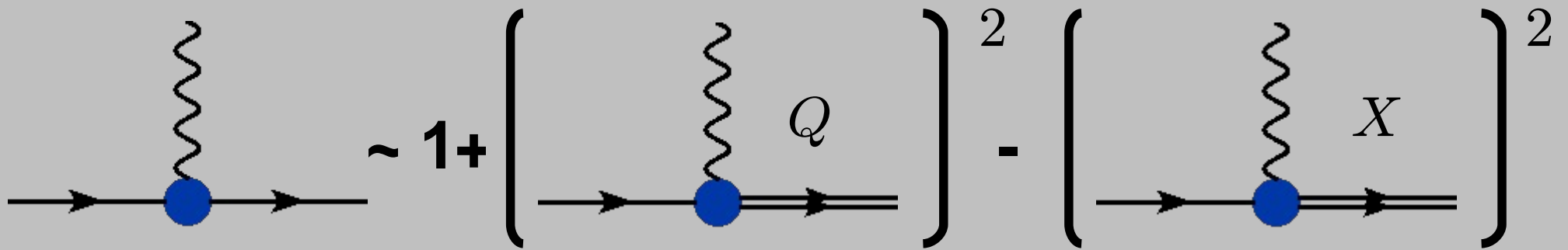
- Also possible for light generations: new very light vector-like quarks with a strong mixing to valence quarks
 - Degenerate doublets with hypercharges 1/6 and 7/6 that mix only with u_R , in the basis of diagonal up Yukawas

$$\mathcal{L} = \mathcal{L}_K - \left[\lambda_u^i \bar{q}_L^{(0)i} \tilde{\varphi} u_R^{(0)i} + \lambda_d^j V_{ij} \bar{q}_L^{(0)i} \varphi d_R^{(0)j} \right. \\ \left. + \lambda_Q (\bar{Q}_L^{(0)} \tilde{\varphi} + \bar{X}_L^{(0)} \varphi) u_R^{(0)} \right. \\ \left. + m_Q (\bar{Q}_L^{(0)} Q_R^{(0)} + \bar{X}_L^{(0)} X_R^{(0)}) + \text{h.c.} \right]$$

Quark Custodians

Atre, Carena, Han, Santiago 09

- Also possible for light generations: new very light vector-like quarks with a strong mixing to valence quarks



$$\sim 1 + \left(\frac{\lambda_Q v}{m_Q} \right)^2 - \left(\frac{\lambda_X v}{m_X} \right)^2$$

- They can be large!!