Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC

Chung Kao
University of Oklahoma
Norman OK

†Presented at the Workshop on Physics Opportunities with LHC at 7 TeV,
KEK, Tsukuba, Japan, February 16--18, 2012

Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC

Kao, Cheng, Hou, and Sayre, **arXiv:1112.1707**

- A Special Two Higgs Doublet Model for the Top
- Flavor Changing Neutral Higgs Boson in Top Decays
- The Physics Background
- Realistic Acceptance Cuts
- The Discovery Potential at the LHC
- Comparison of Production Rates
- Conclusions

A Special Two Higgs Doublet Model for the Top Quark

Das and Kao (1996)

- We propose that the top quark is the only elementary fermion getting a mass from a much larger VEV of a second Higgs doublet.
- The top quark is naturally heavier than other quarks and leptons in the 3 known generations.
- The ratio of the Higgs VEVs, tan(beta)= $|v_2|/|v_1|$, is naturally large, which enhances the Yukawa couplings of the lighter quarks and leptons with the Higgs bosons.
- There are flavor changing neutral Higgs (FCNH) interactions among the up type quarks.

A Special Two Higgs Doublet Model for the Top Quark

We choose the Lagrangian density of Yukawa interactions be of the following form:

$$\mathcal{L}_Y = -\sum_{m,n=1}^{3} \bar{L}_L^m \phi_1 E_{mn} l_R^n - \sum_{m,n=1}^{3} \bar{Q}_L^m \phi_1 F_{mn} d_R^n - \sum_{\alpha=1}^{2}\sum_{m=1}^{3} \bar{Q}_L^m \tilde{\phi}_1 G_{m\alpha} u_R^\alpha - \sum_{m=1}^{3} \bar{Q}_L^m \tilde{\phi}_2 G_{m3} u_R^3 + \text{H.c.}$$

Flavor Changing Neutral Higgs Interactions in Top Decays

Kao, Cheng, Hou, and Sayre, **arXiv:1112.1707**

- Let us consider the following Lagrangian involving flavor changing neutral Higgs interactions with top and charm quarks:

$$\mathcal{L} = -\lambda_{tc}\bar{t}cH^0 - i\lambda_{tc}\bar{t}\gamma_5 cA^0 + \mathrm{H.c.}$$

  where H^0 is a scalar and A^0 is a pseudoscalar.

- This is a general feature of Model III of Yukawa Interactions in Two Higgs Doublet Models.

FCNH Yukawa Coupling

Cheng and Sher (1987)

- Let us consider the FCNH coupling of tcH to be the geometric mean of the Yukawa couplings of the quarks:

$$\lambda_{tc} = \frac{\sqrt{m_t m_c}}{v}$$

- In general, we will take it as a free parameter.

Top Decay Width

Hou (1991)

- The FCNH top decay with is

$$\Gamma(t \to c\phi^0) \quad = \quad \frac{|\lambda_{tc}|^2}{16\pi} \times (m_t) \times [(1 \pm \rho_c)^2 - \rho_\phi^2]$$
$$\times \sqrt{1 - (\rho_\phi + \rho_c)^2} \sqrt{1 - (\rho_\phi - \rho_c)^2}$$

rho$_c$ = m_c/m_t, rho$_H$ = M_H/m_t, + for H^0 and - for A^0.

- The total width is

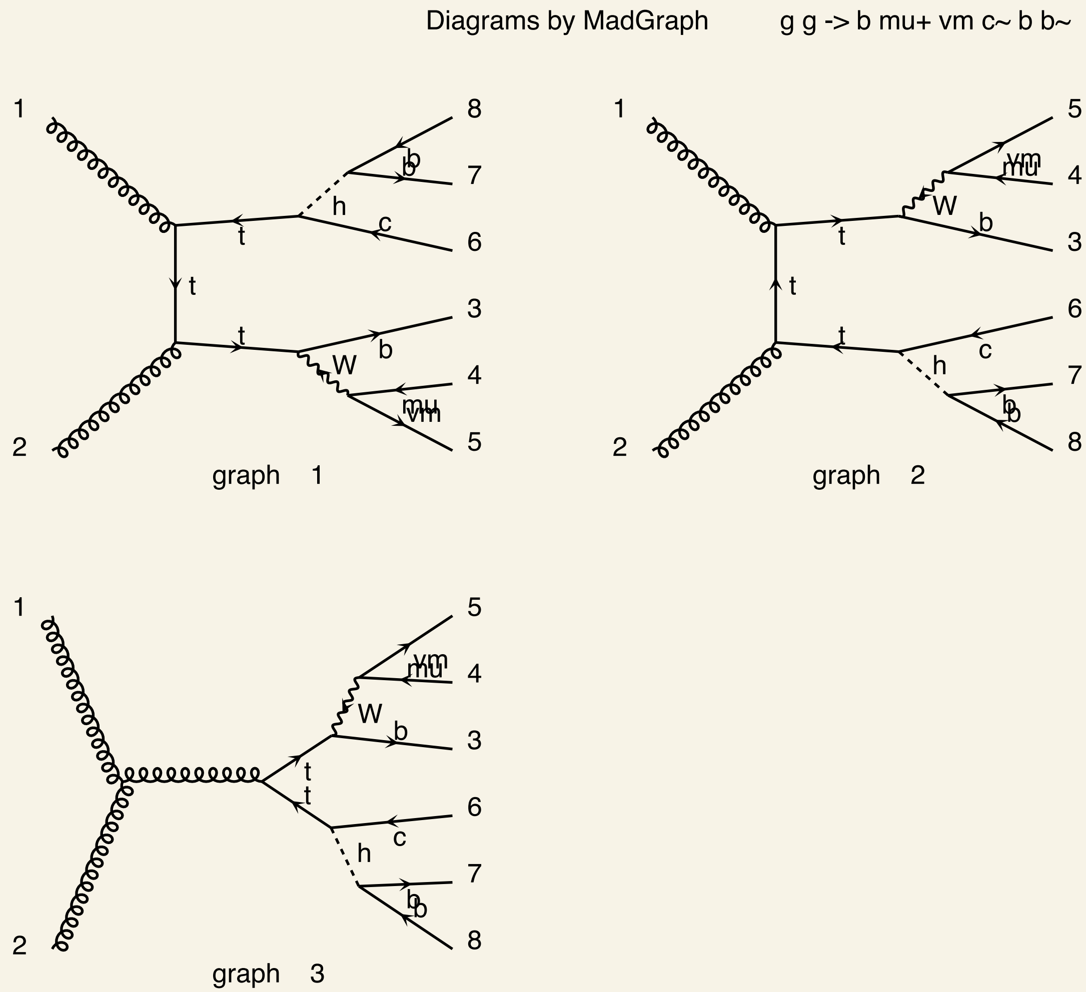
$$\Gamma_t = \Gamma(t \to bW) + \Gamma(t \to c\phi^0)$$

FCNH Branching Fraction

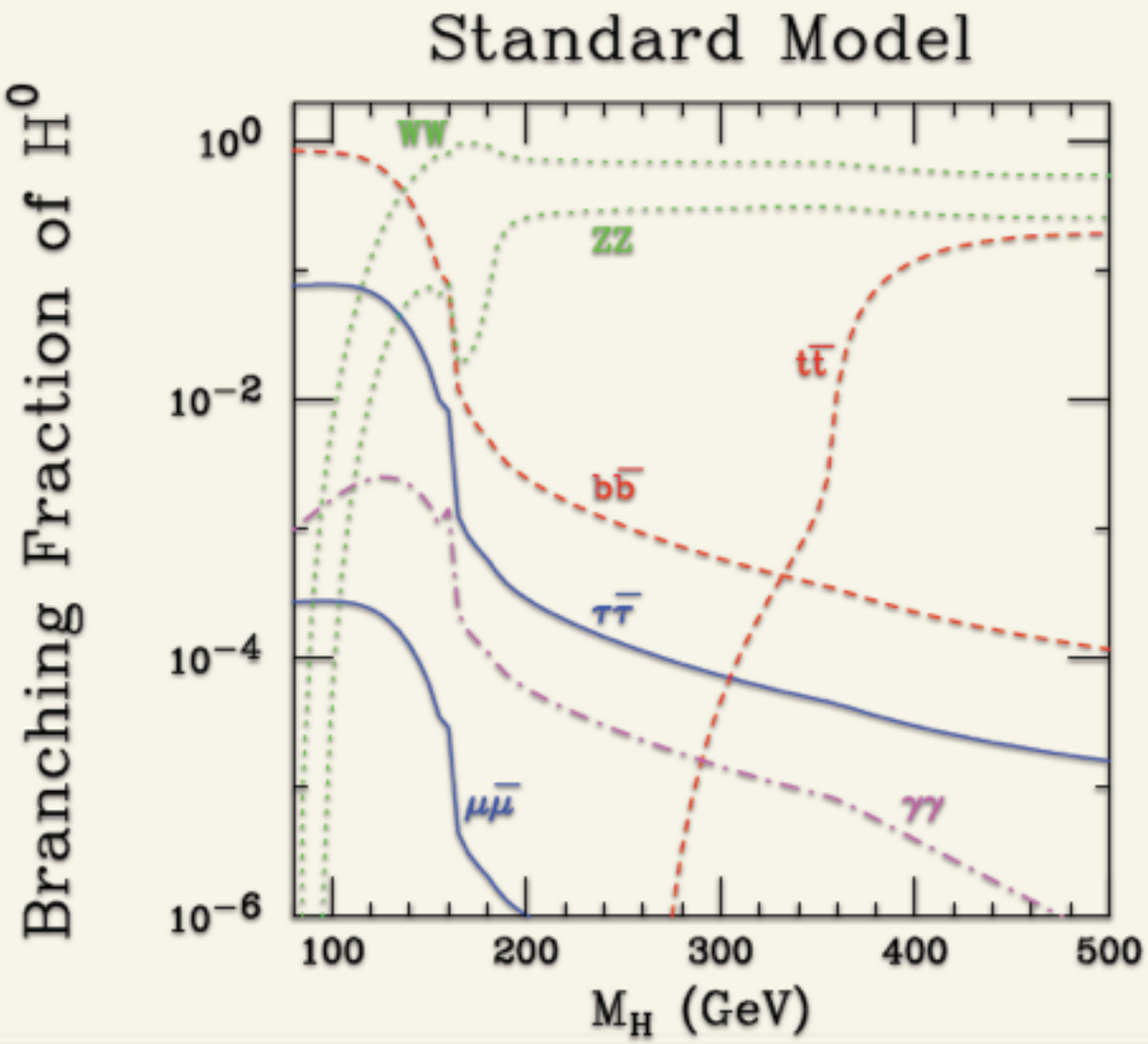
As a case study, we take the FCNH Yukawa couplings to be the geometric mean of the Yukawa couplings of the quarks with m_t = 173.3 GeV and m_c = 1.4 GeV:

$$
\begin{aligned}
\lambda_{tc} &= \frac{\sqrt{m_t m_c}}{v} \simeq 0.063 \\
\mathcal{B}(t \to c\phi^0) &= 2.6 \times 10^{-3} \quad \text{for } M_\phi = 120 \text{ GeV}\,, \\
\mathcal{B}(t \to c\phi^0) &= 6.2 \times 10^{-4} \quad \text{for } M_\phi = 150 \text{ GeV}\,.
\end{aligned}
$$

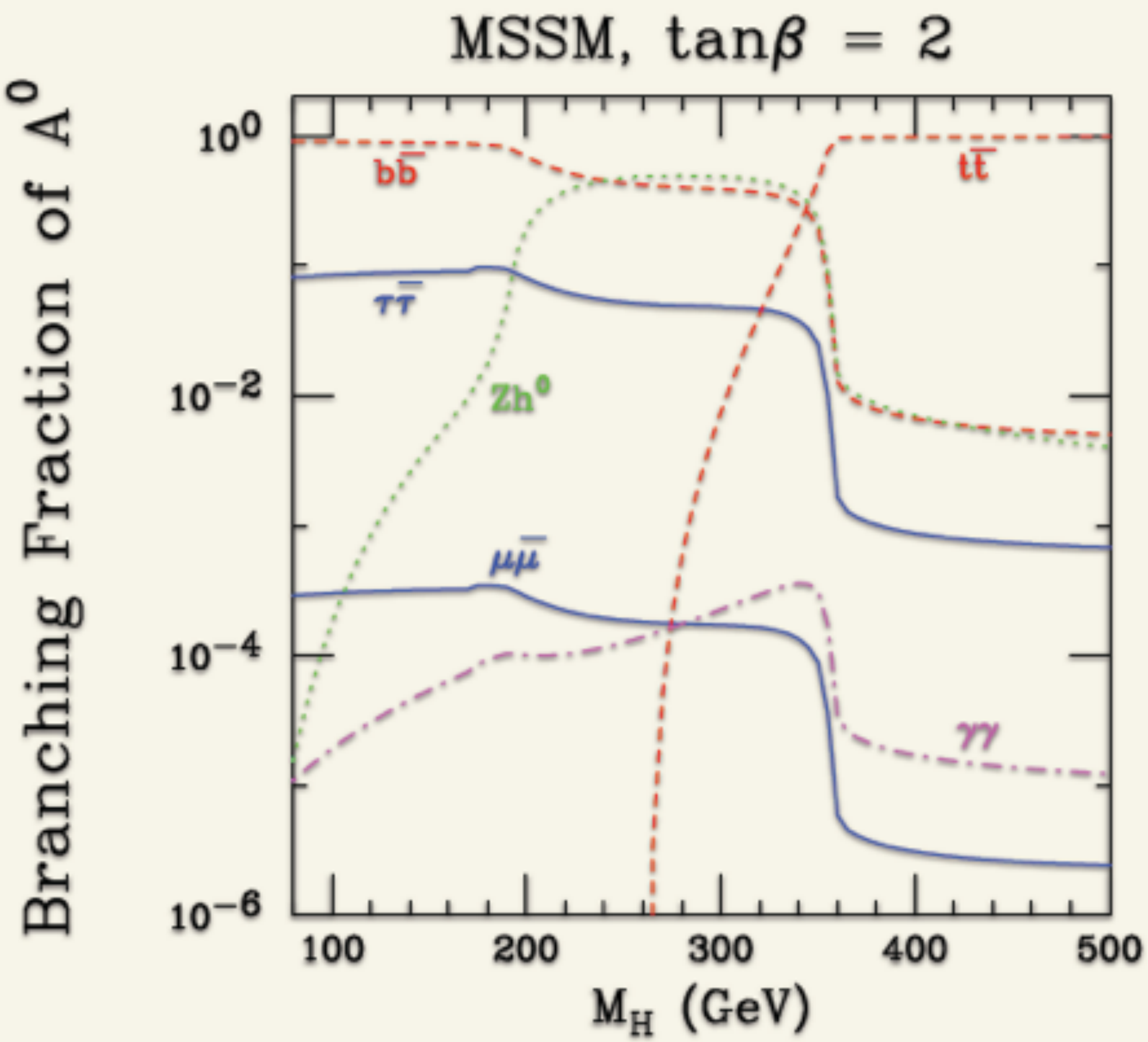
The FCNH Signal



Branching Fractions of the Higgs Boson



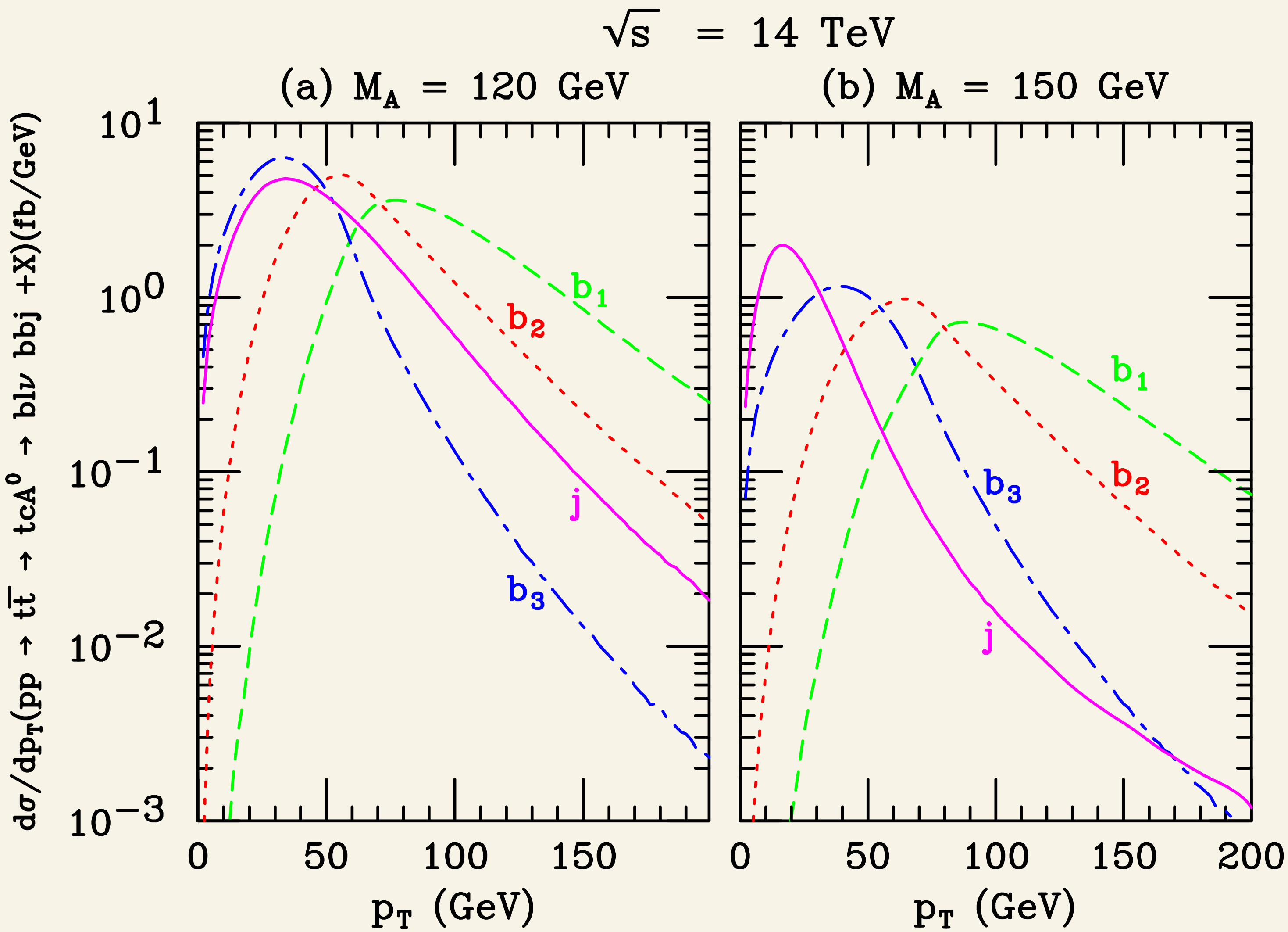
Branching Ratios of a Higgs Pseudoscalar



The FCNH Signal at the LHC

- We employ the programs MadGraph and HELAS to evaluate the exact matrix element for the FCNH signal from gluon fusion and quark-antiquark annihilation in pp collisions.
  Stelzer and Long (1994); Alwall et al. (2007); Murayama, Watanabe and Hagiwara (1991).
- In addition, we apply narrow width approximation to check the exact results.
- The cross sections are evaluated with the parton distribution functions of CTEQ6L1.

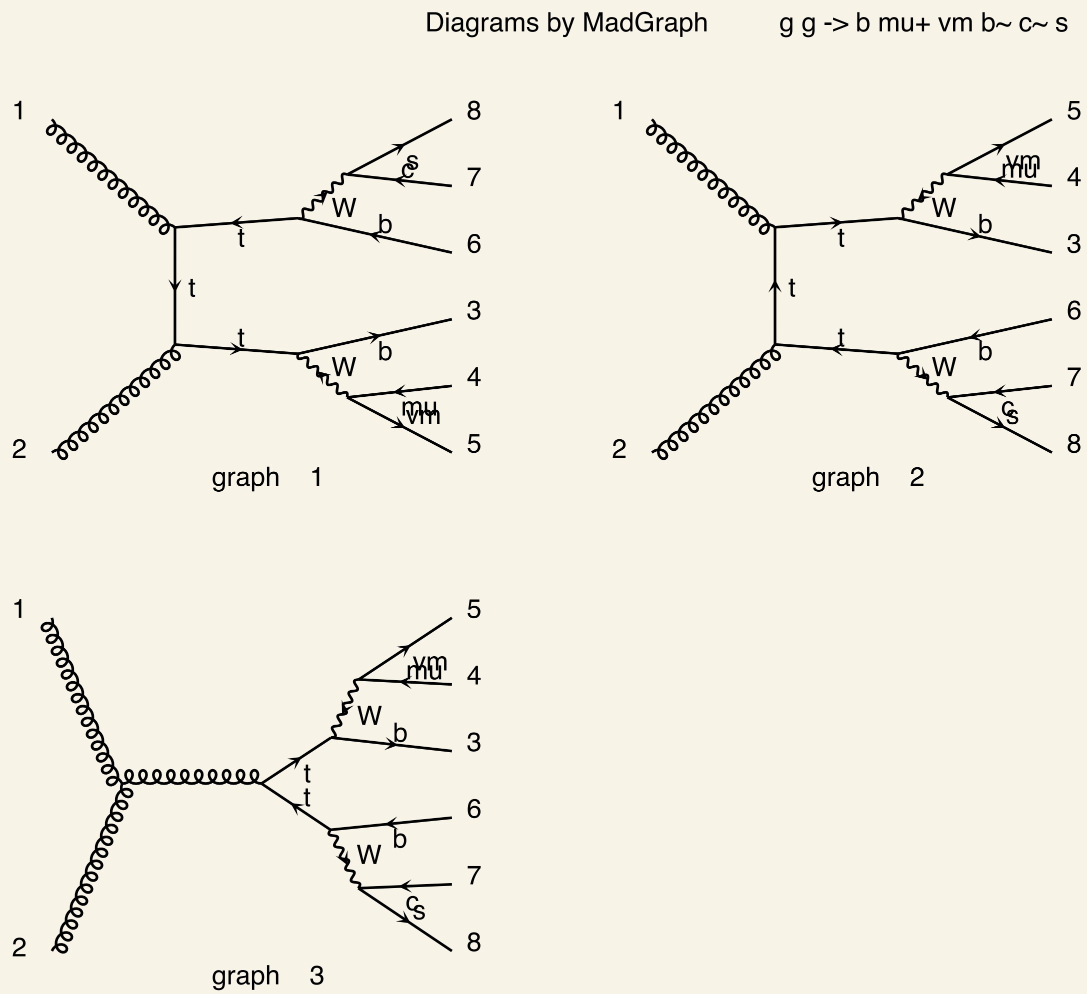
Transverse Momentum Distribution for the Higgs Signal



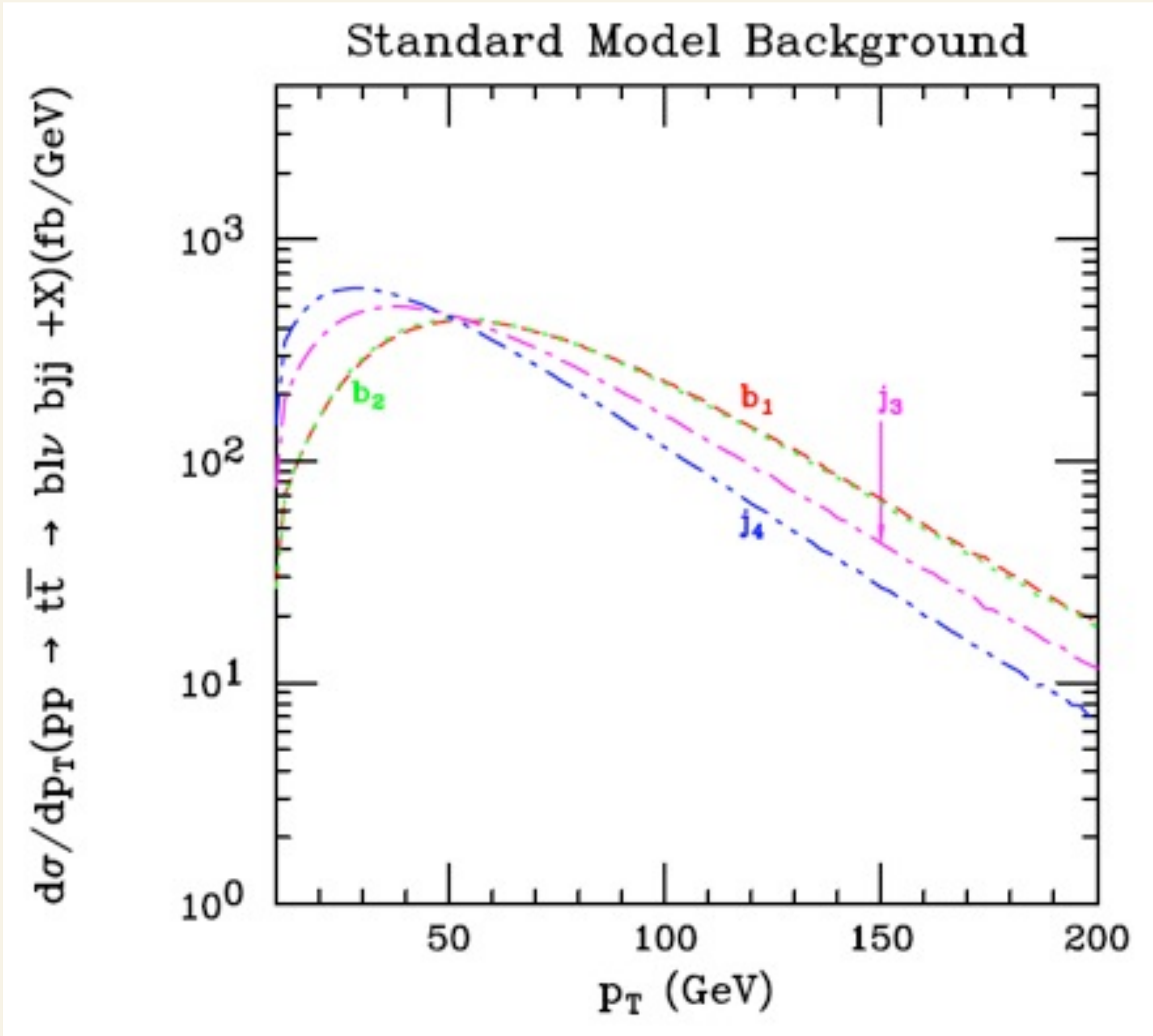
FCNH Signal Cross Section

M_A	s(bmncbb)	B(t cH)	Gamma(H)	B(H bb)
120.0	0.440E+02	0.259E-02	0.351E-02	0.728E+00
140.0	0.820E+01	0.117E-02	0.428E-02	0.677E+00
150.0	0.268E+01	0.621E-03	0.473E-02	0.649E+00

Dominant Physics Background from top quark pairs



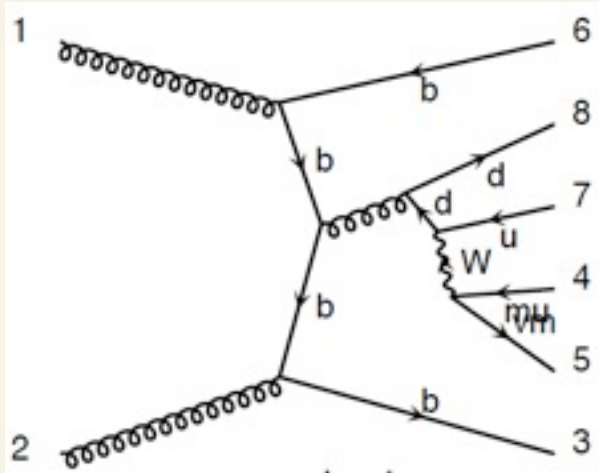
Transverse Momentum Distribution for the Physics Background



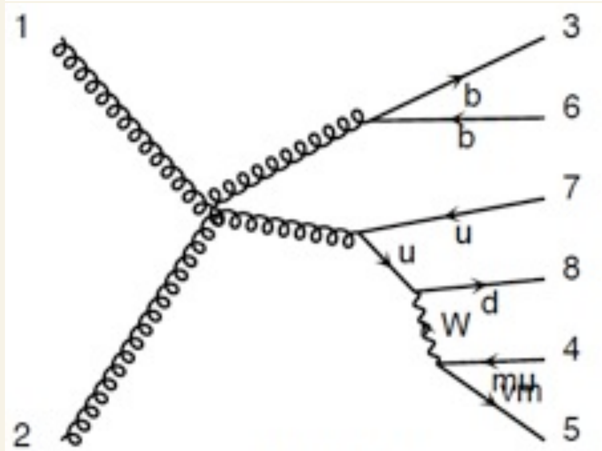
Additional Backgrounds

gg, qq to Wbbjj

- We have included additional backgrounds with Wbbjj:
- gg to Wbbjj
- $q_v q_v$ to Wbbjj
- gq to Wbbjj
- $q_v q_s$ to Wbbjj



graph 1

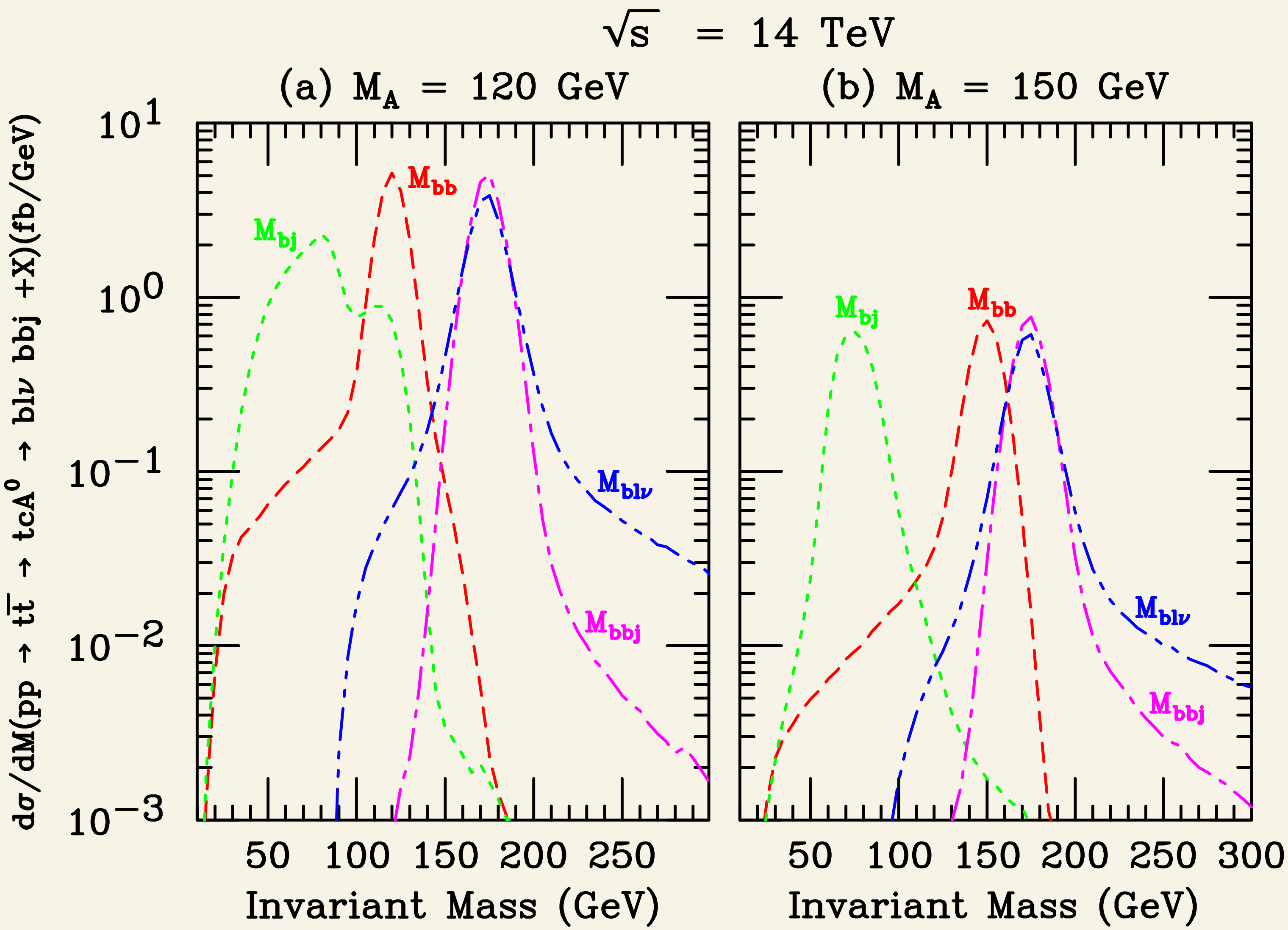


graph 102

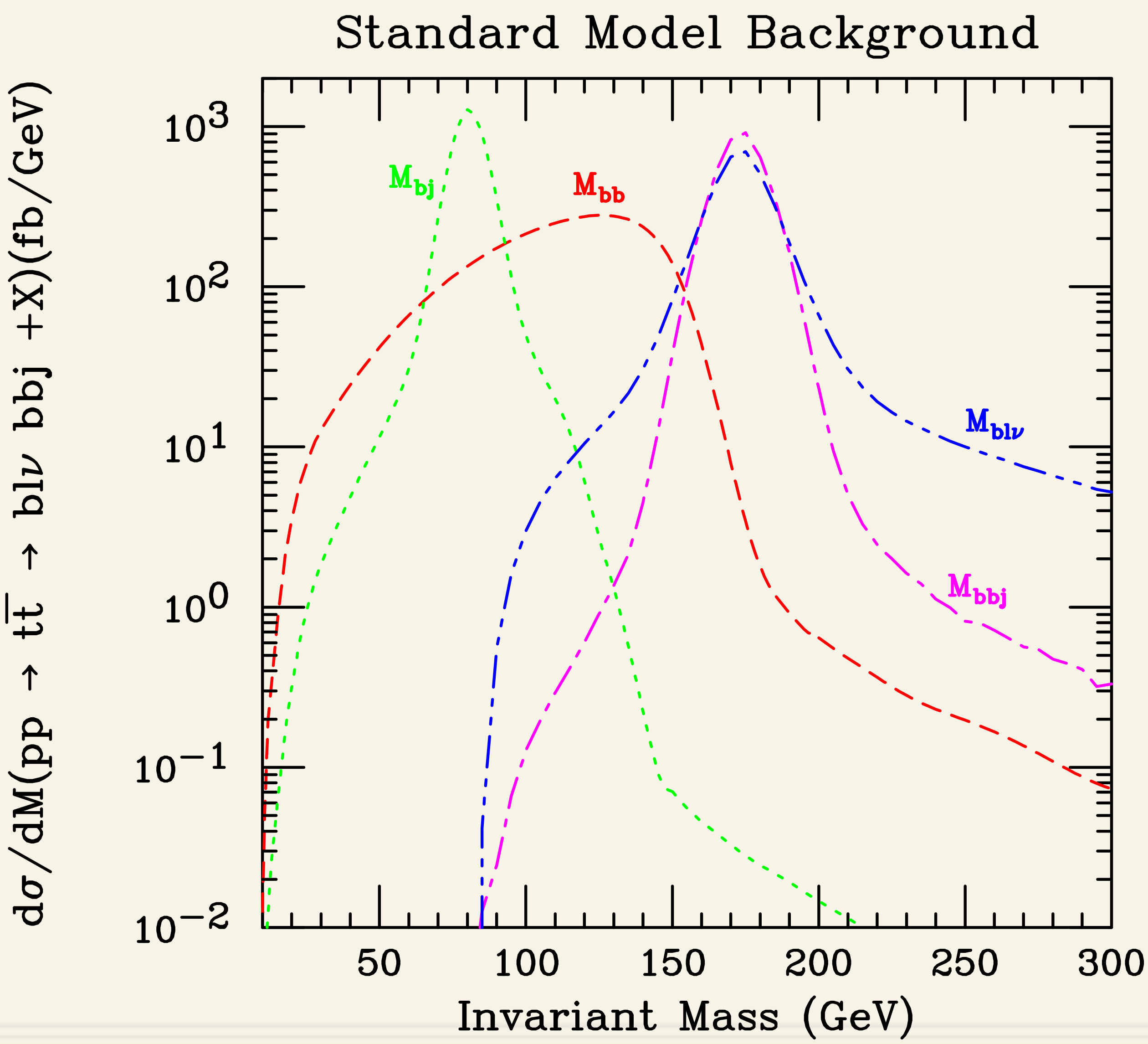
Mass Reconstruction

- Since our FCNC signal comes from one top quark decay, we will choose the pair of b jets that minimize $|M_{bbj}-m_t|$ as b_1b_2 and label the other b jet as b_3.
- For a correctly reconstructed event, b_1 and b_2 are the products of a Higgs decay as well, such that their invariant mass has a peak near M_H.
- For a background event, we identify b_2 as the member of this pair that minimizes $|M_{bj}-m_{W}|$.
- The remaining b quark (b_3) should reproduce m_t with the charged lepton and neutrino momenta.

Invariant Mass: FCNH Signal



Invariant Mass: Physics Background



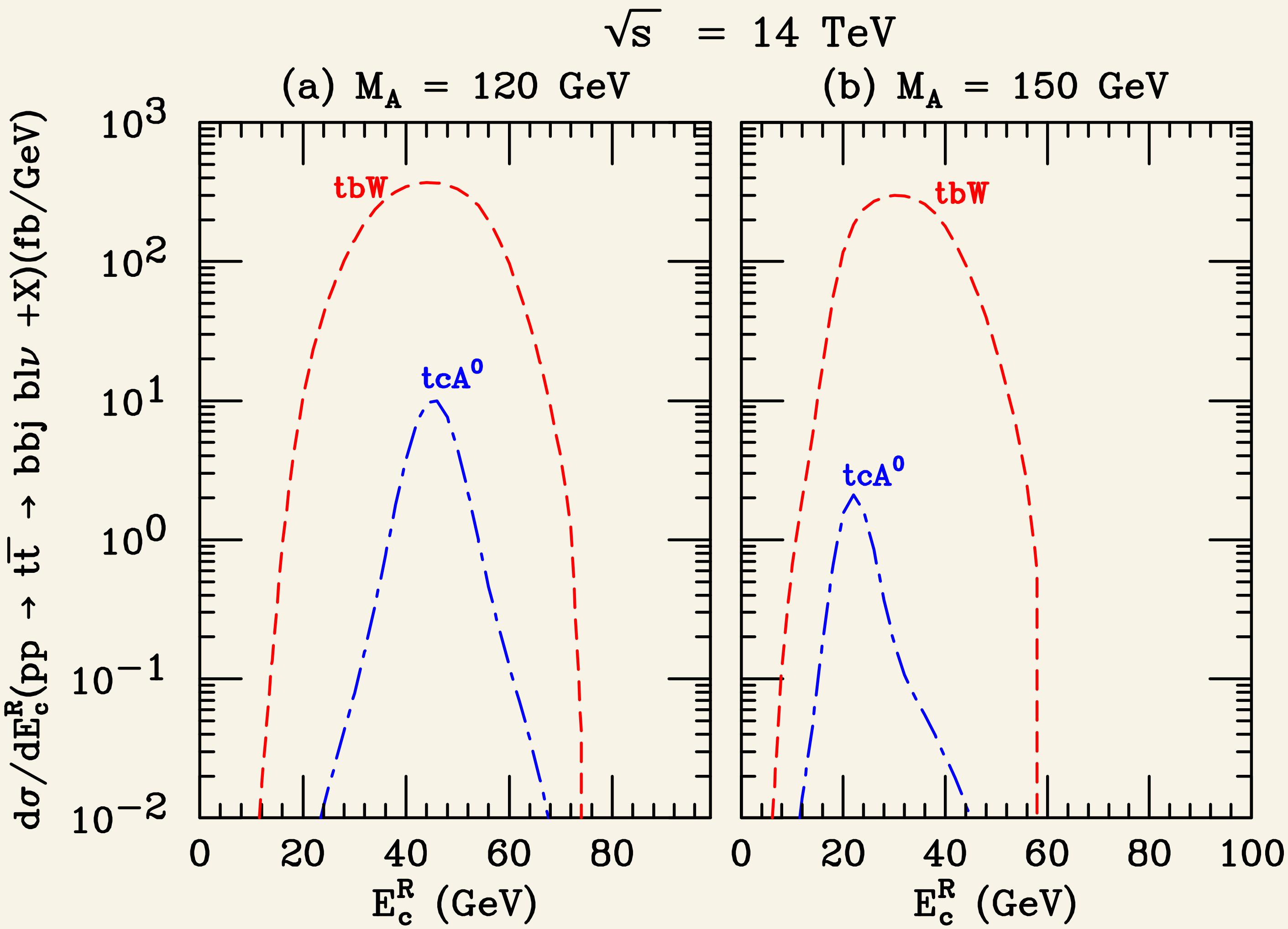
Realistic Acceptance Cuts

For (a) the early LHC and (b) full CM energy with low luminosity, we require that in every event there should be

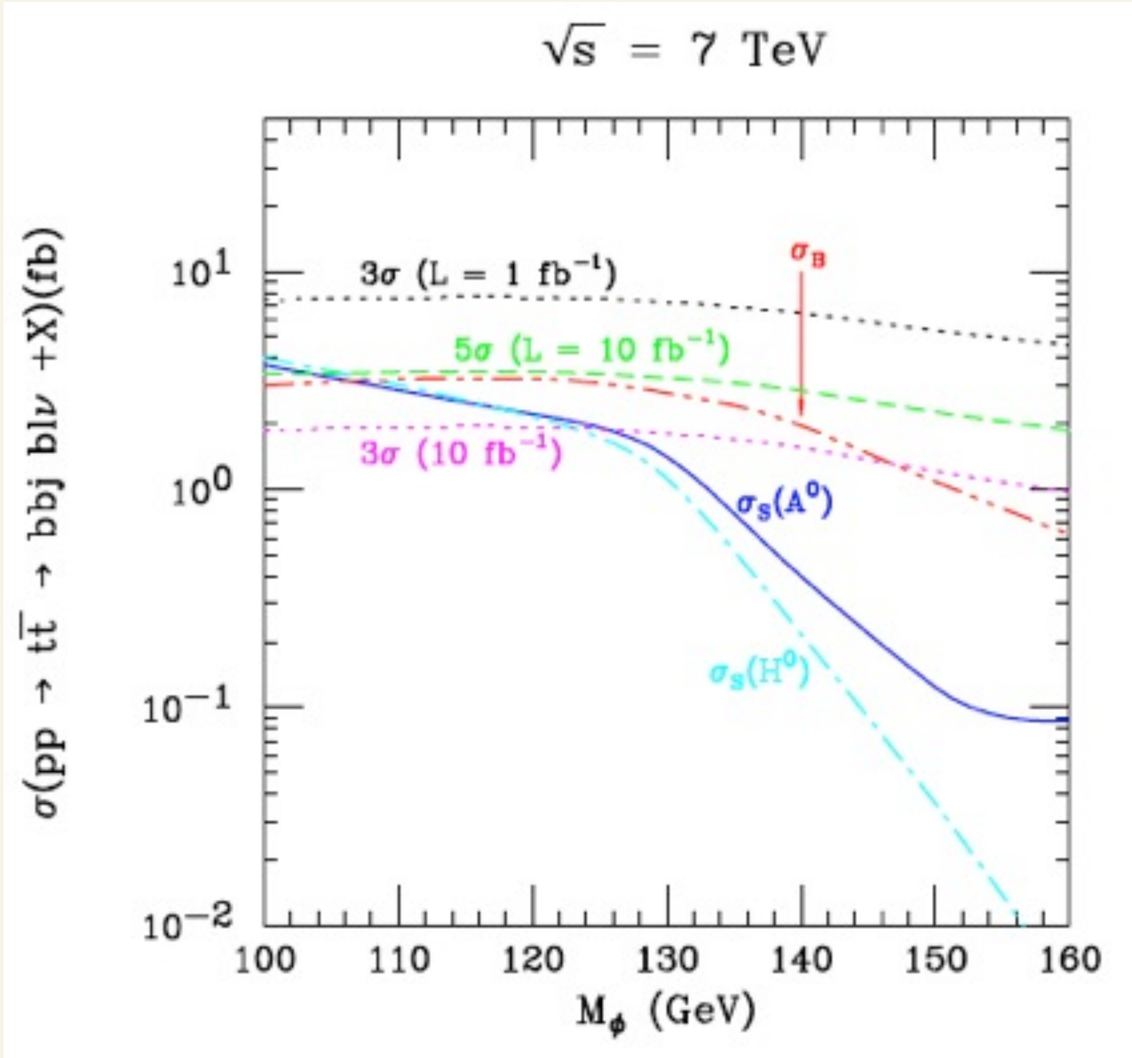
- exactly 4 jets that have $p_T > 15$ GeV and $|\eta| < 2.5$, and three of them must be tagged as b-jets;
- exactly one isolated lepton that has $p_T > 20$ GeV and $|\eta| < 2.5$;
- the missing transverse energy ($\not{E}_T$) must be greater than 20 GeV;
- at least one pair of b-jets such that the invariant mass of $b_1 b_2 j$ should be near m_t: $|M_{b_1 b_2 j} - m_t| \leq 25$ GeV;
- the pair of b-jets, $b_1 b_2$, that reconstructs the hadronically decaying top should also satisfy $|M_{b_1 b_2} - M_\phi| \leq 0.15 M_\phi$;
- a third b jet such that the invariant mass of $b_3 \ell \nu$ should be near m_t: $|M_{b_3 \ell \nu} - m_t| \leq 25$ GeV;
- the reconstructed leptonic W must satisfy $|M_{\ell\nu} - m_W| \leq 15$ GeV.

Reconstructed E_{charm}

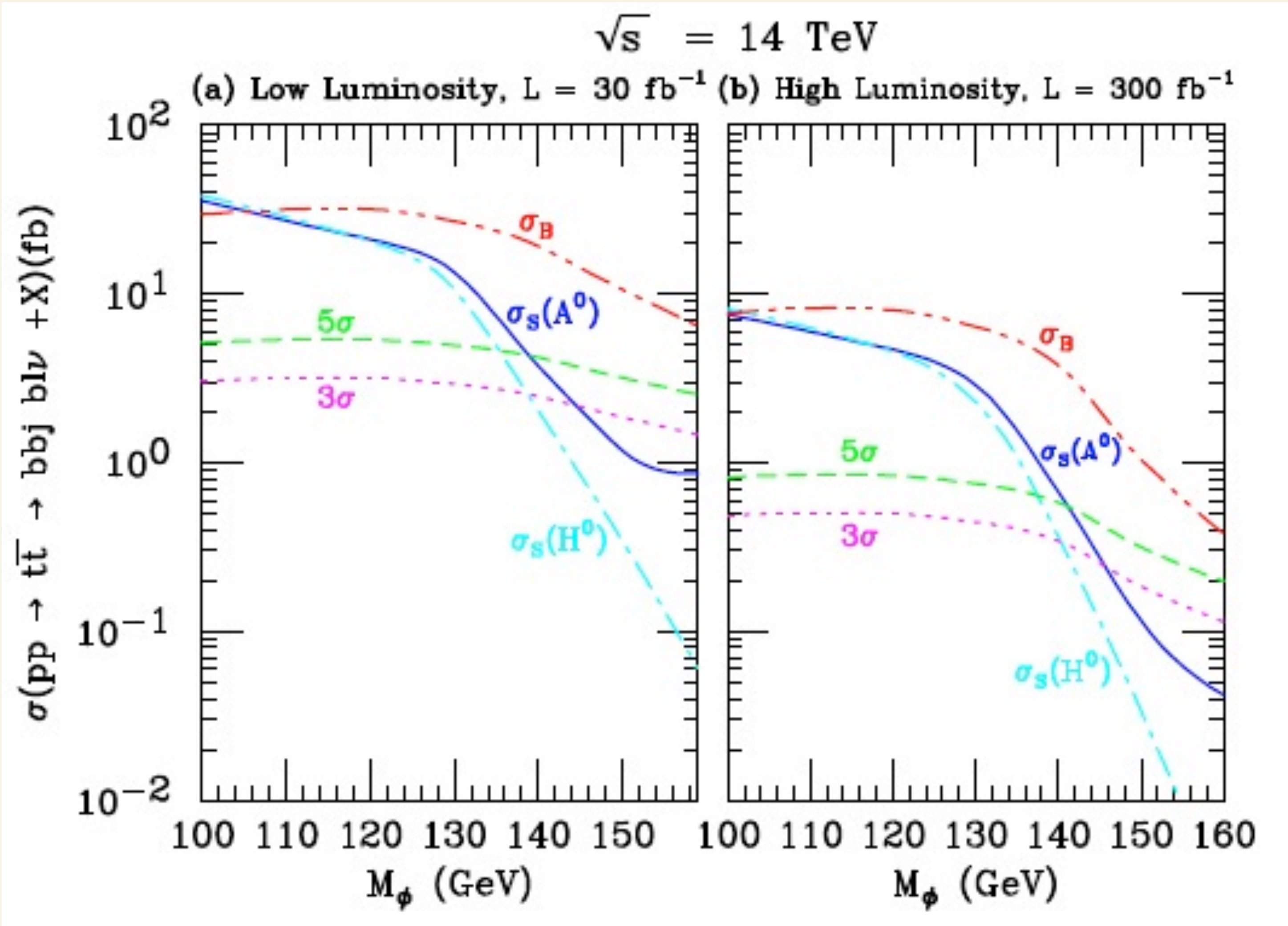
Han, Jiang, and Sher (2001)



Signal versus Background

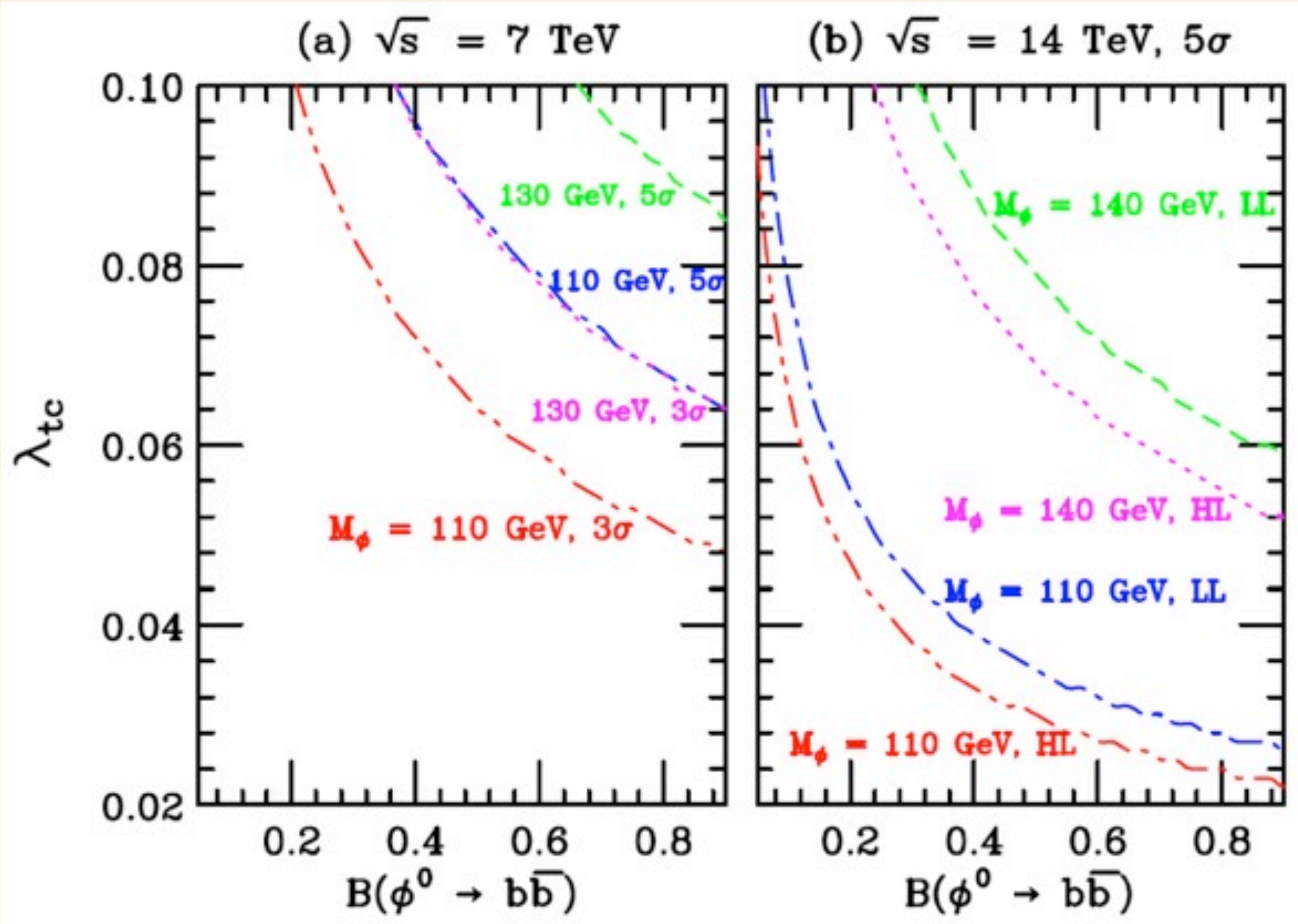


Signal versus Background



Discovery Contours

L = 10 fb^{-1} at 7 TeV



Comparison of Production Rates with H_T(jets+leptons)

Kao, Cheng, Hou, and Sayre (2011)

Aguilar-Saavedra and Branco (2000)

	Low Luminosity (10 fb^{-1})		High Luminosity (100 fb^{-1})	
	Before Cuts	Standard Cuts	Before Cuts	Standard Cuts
Signal	200 (267)	46.7 (98.2)	1630 (2150)	394 (797)
$t\bar{t}$	5491 (7186)	20.2 (33.2)	44540 (58230)	174 (270)
$Wbbjj$	58 (77)	0.232 (0.3)	476 (644)	2.00 (2.2)

Comparison of Production Rates with H_T(jets)

Kao, Cheng, Hou, and Sayre (2011)

Aguilar-Saavedra and Branco (2000)

	Low Luminosity (10 fb^{-1})		High Luminosity (100 fb^{-1})	
	Before Cuts	Standard Cuts	Before Cuts	Standard Cuts
Signal	200 (267)	30.4 (98.2)	1630 (2150)	251 (797)
$t\bar{t}$	5491 (7186)	10.1 (33.2)	44540 (58230)	83.9 (270)
$Wbbjj$	58 (77)	0.085 (0.3)	476 (644)	0.680 (2.2)

Conclusions

- At the LHC, it is promising to detect FCNH top decays for $\lambda_{tc} > 0.02$ and $M_H < 140$ GeV.
- For $M_H > 150$ GeV, most c-jets are removed by acceptance cuts.
- Higher energy and higher luminosity can improve the discovery reach significantly.
- We might find out if nature chooses the same mechanisms for electroweak symmetry breaking and FCNC.

Bonus

Discovering Colorons at the LHC

Dicus, Kao, Nandi, and Sayre, **arXiv:1012.5694; arXiv:1105.3219**

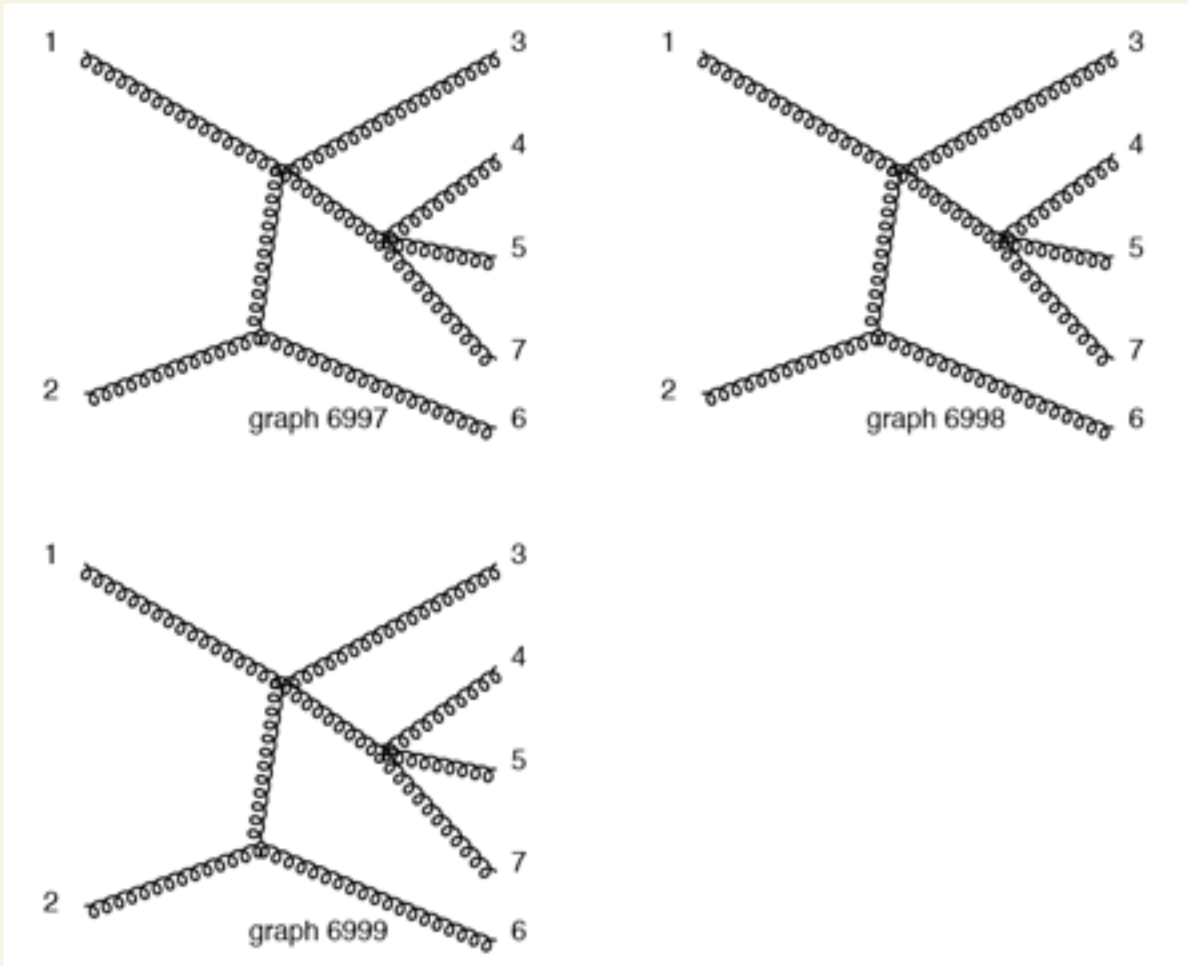
Production of Coloron Pairs

- Signal: $pp \to \tilde{\rho}\tilde{\rho} \to 4\tilde{\pi} \to 8g + X$
- Cross sections of signal evaluated with analytical formulas are in good agreement with results from MadGraph.
- Dominant Physics Background: $pp \to 8g + X$ calculated with COMIX using Berends-Giele recursion relations, and checked with MadGraph for $gg \to 4g$

Limitations of MadGraph

Skipping 7245 6999, There are 6999 graphs

Page 875



Recursion Relations in QCD

Duhr, Hoche and Maltoni (2006)

- Berends and Giele [1988]
- Cachazo, Svrcek and Witten (CSW) [2004]
- Britto, Cachazo and Feng (BCF)[2005]
- Britto, Cachazo, Feng, and Witten (BCFW)[2005]

Final State	BG		BCF		CSW	
	CO	CD	CO	CD	CO	CD
$2g$	0.24	0.28	0.28	0.33	0.31	0.26
$3g$	0.45	0.48	0.42	0.51	0.57	0.55
$4g$	1.20	1.04	0.84	1.32	1.63	1.75
$5g$	3.78	2.69	2.59	7.26	5.95	5.96
$6g$	14.2	7.19	11.9	59.1	27.8	30.6
$7g$	58.5	23.7	73.6	646	146	195
$8g$	276	82.1	597	8690	919	1890
$9g$	1450	270	5900	127000	6310	29700
$10g$	7960	864	64000	-	48900	-