SUSY, Technicolor, Little Higgs and Inverse problem

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OUTLINE

- What is the Inverse problem?
- Discriminating SM, SUSY and Technicolor through the Higgs boson signatures
- Little Higgs model with T-parity (LHT)
- Phenomenology and Signatures
- The problem of Discriminating from SUSY
- Conclusions

Inverse Problem

- Actually, without specifying the model, there is no inverse problem
- Once your best model (e.g. SUSY) or set of best alternatives (including Little Higgs models, Technicolor, models with extra dimensions, or general model based on the effective Lagrangian approach)
  is specified, inverse problem comes into play
- Before solving the inverse problem – understanding the underlying theory, we should understand all possible patterns, i.e. do study inverse to inverse

Problems of the Standard Model

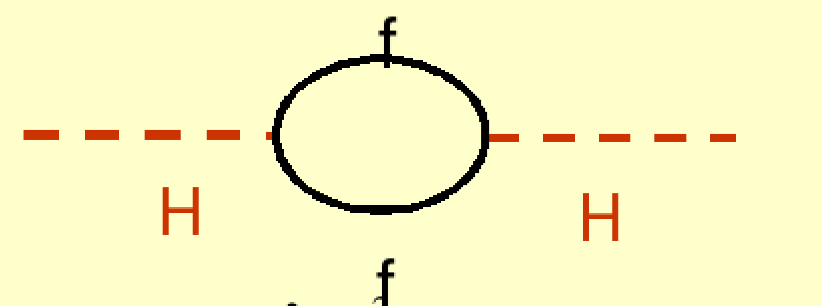
- Problem of large quantum corrections to the Higgs mass in SM (Hierarchy problem)
- Coupling Unification
- The origin of Electroweak Symmetry breaking.

  Higgs boson is not found yet

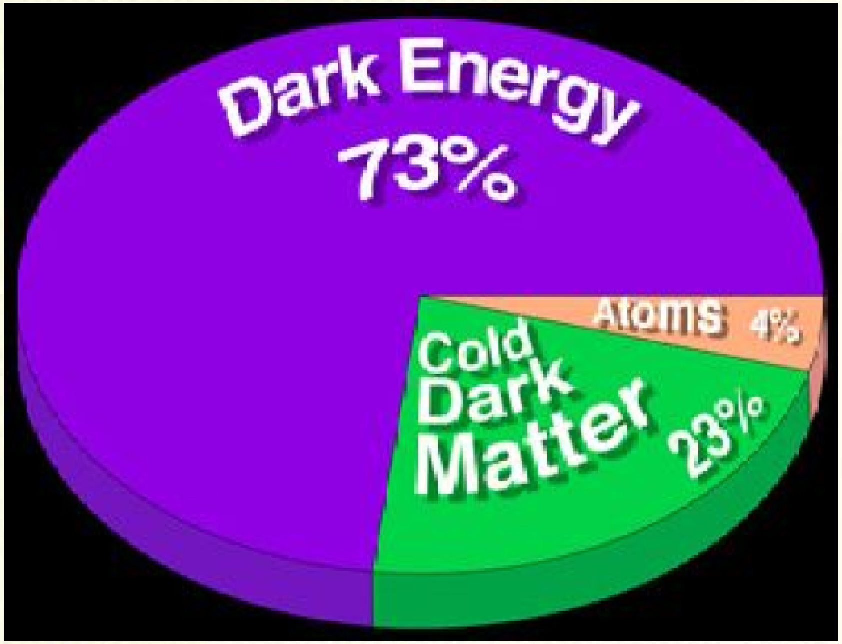
  …
- The origin and Nature of

  Dark Matter and Dark Energy

  No explanation within SM …
- Baryogenesis problem



$$\delta m_H^2 = \frac{|\lambda_f|^2}{16\pi^2}[-2\Lambda_{UV}^2 + \ldots]$$



Discriminating the nature of EWSB: SUSY and Technicolor

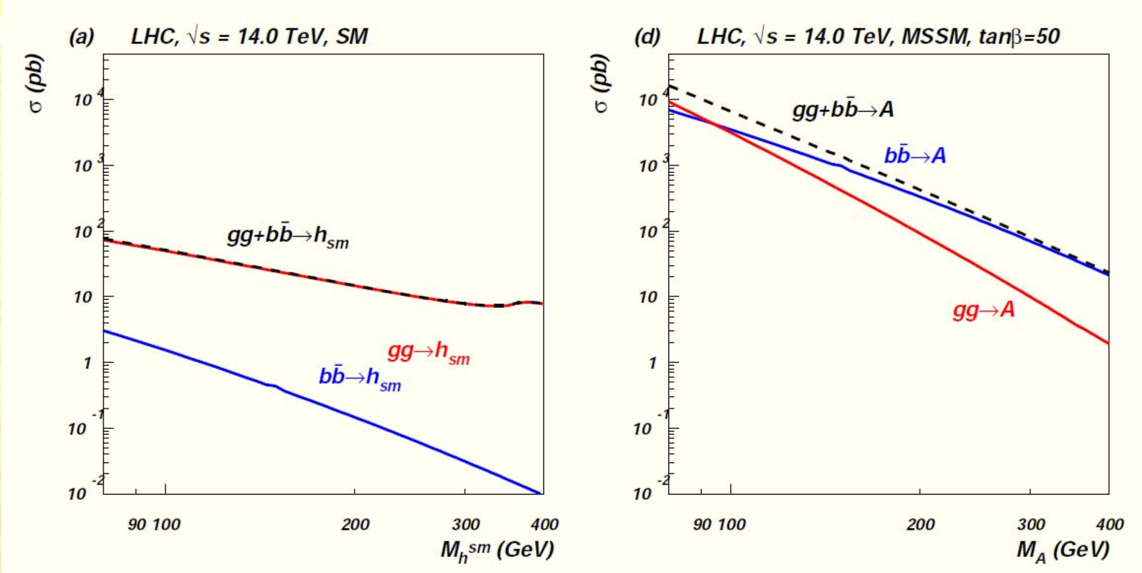
- **Related talks given by J. Wells and K. Tobe**
- **SUSY pattern**

$\tan\beta = v_u/v_d$ *and* M_A *define the Higgs sector at tree level*

Large M_A $\Rightarrow Y_{Hb\bar{b}}/Y^{SM}_{hb\bar{b}} = Y_{H\tau\bar{\tau}}/Y^{SM}_{h\tau\bar{\tau}} \simeq \tan\beta,$

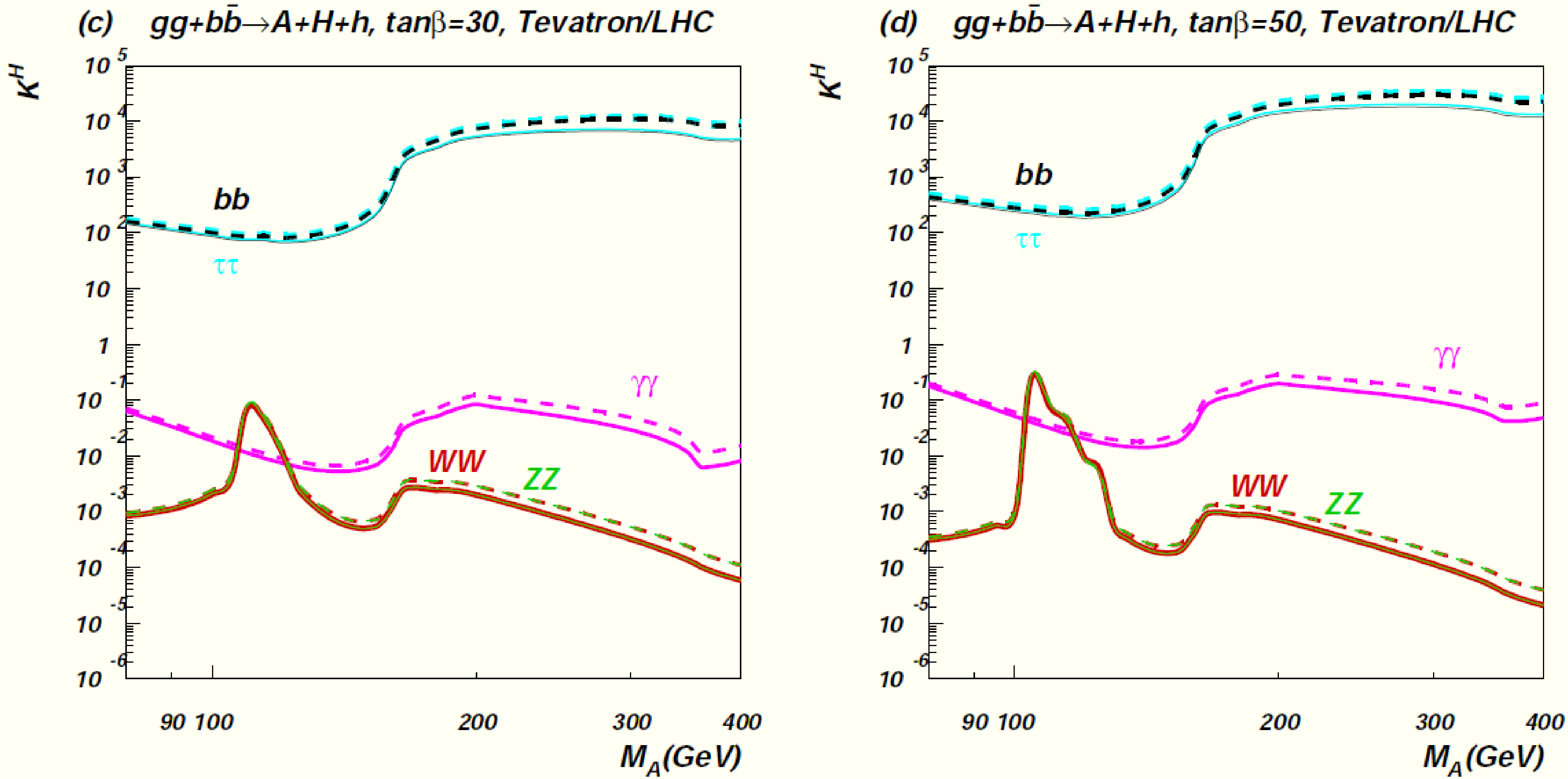
Small $M_A \simeq M_h$ $\Rightarrow Y_{hb\bar{b}}/Y^{SM}_{hb\bar{b}} = Y_{h\tau\bar{\tau}}/Y^{SM}_{h\tau\bar{\tau}} \simeq \tan\beta$

$(Y_{hb\bar{b}}, Y_{Ab\bar{b}})$ *or* $(Y_{hb\bar{b}}, Y_{Ab\bar{b}})$ *are enhanced at large* $\tan\beta$*!*



Total enhancement of $xx \to \mathcal{H} \to yy$ channel

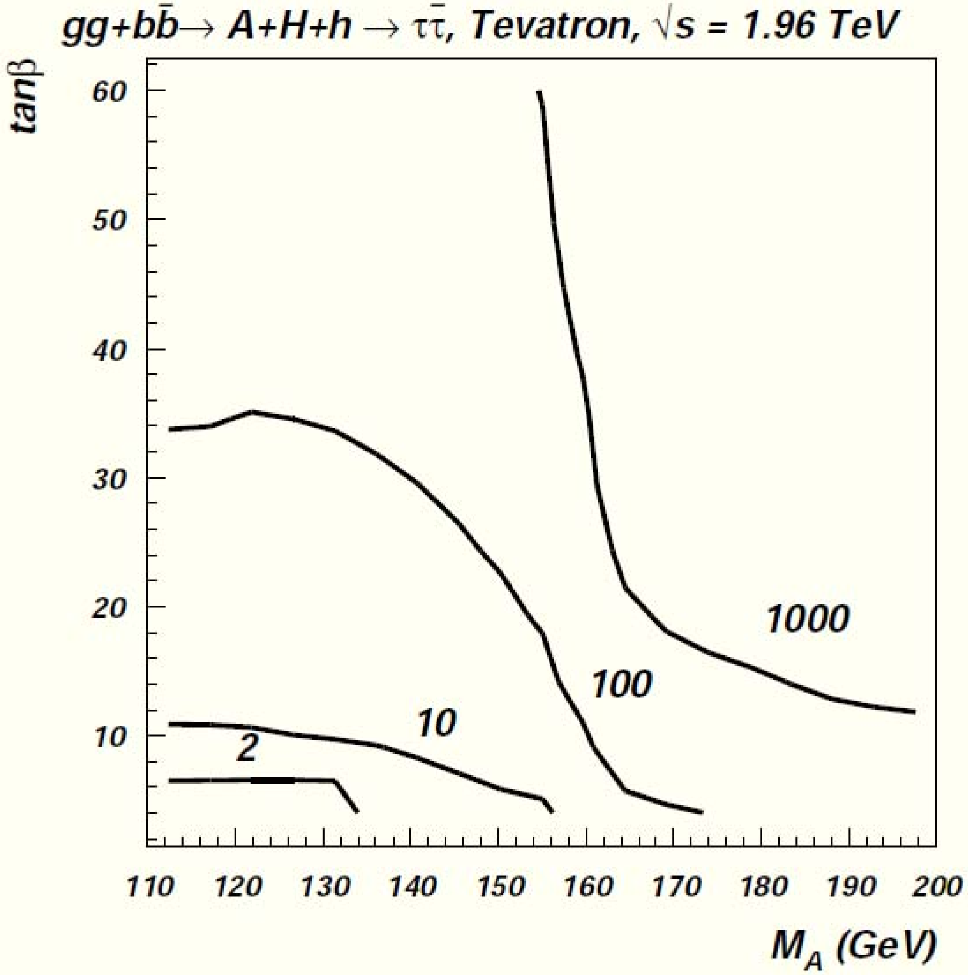
$$\kappa^{\mathcal{H}}_{total/xx} = [\kappa^{\mathcal{H}}_{gg/xx} + \kappa^{\mathcal{H}}_{bb/xx} R_{bb:gg}]$$

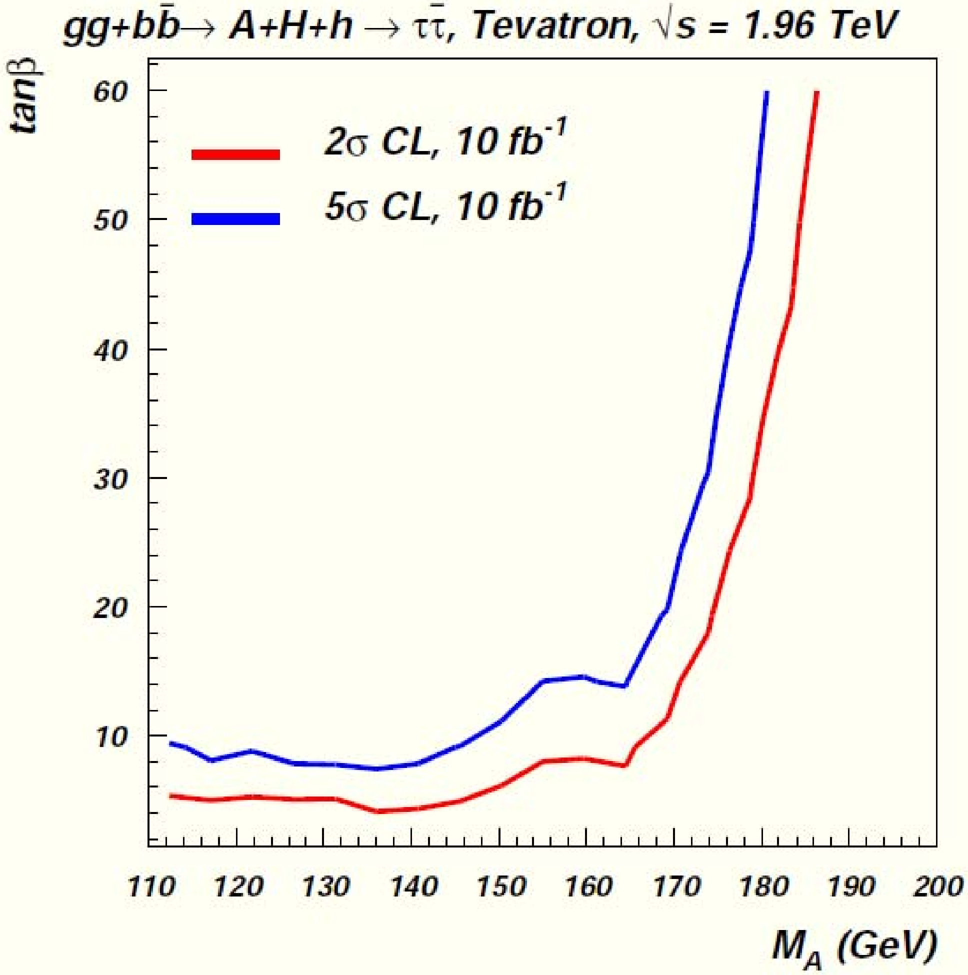


Visibility of MSSM Higgs bosons: $\tau\tau$ channel

Predicted Tevatron reach, based on the $h_{SM} \to \tau^+\tau^-$ studies

by A.B., T.Han, R.Rosenfeld, hep-ph/0204210

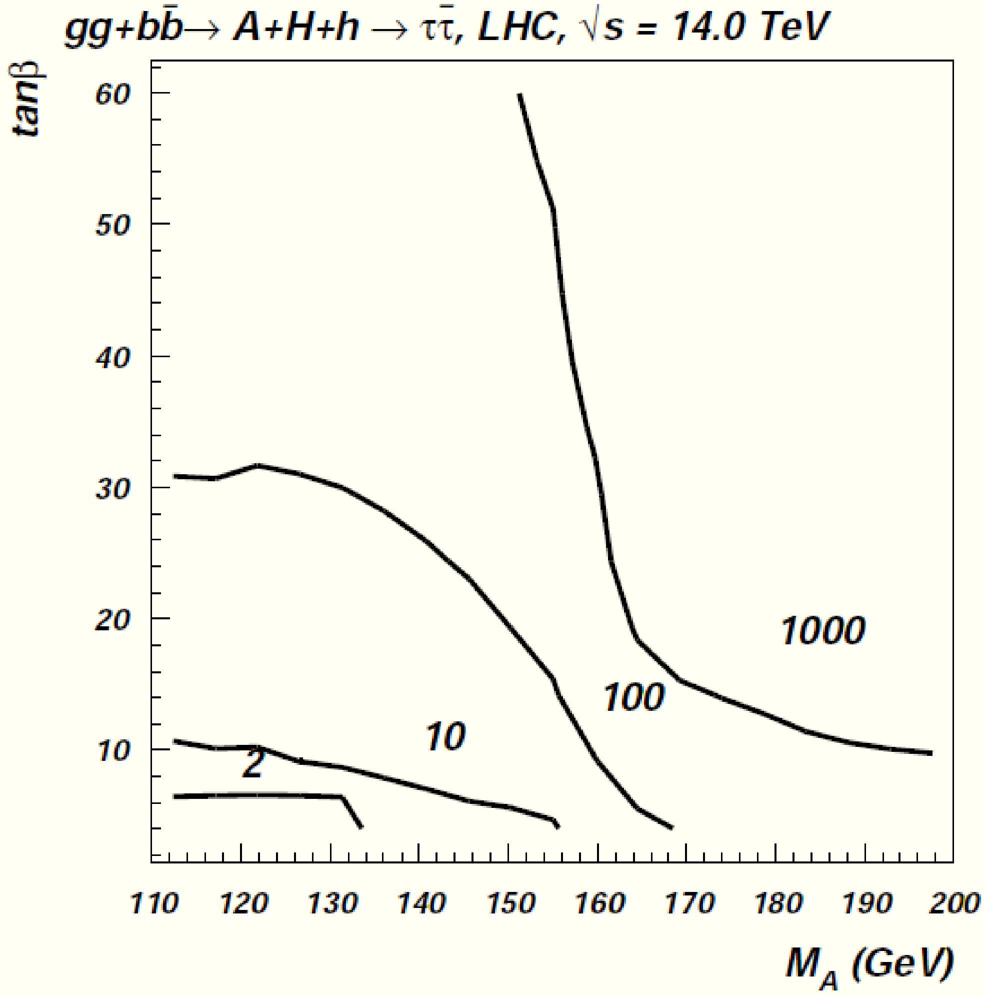


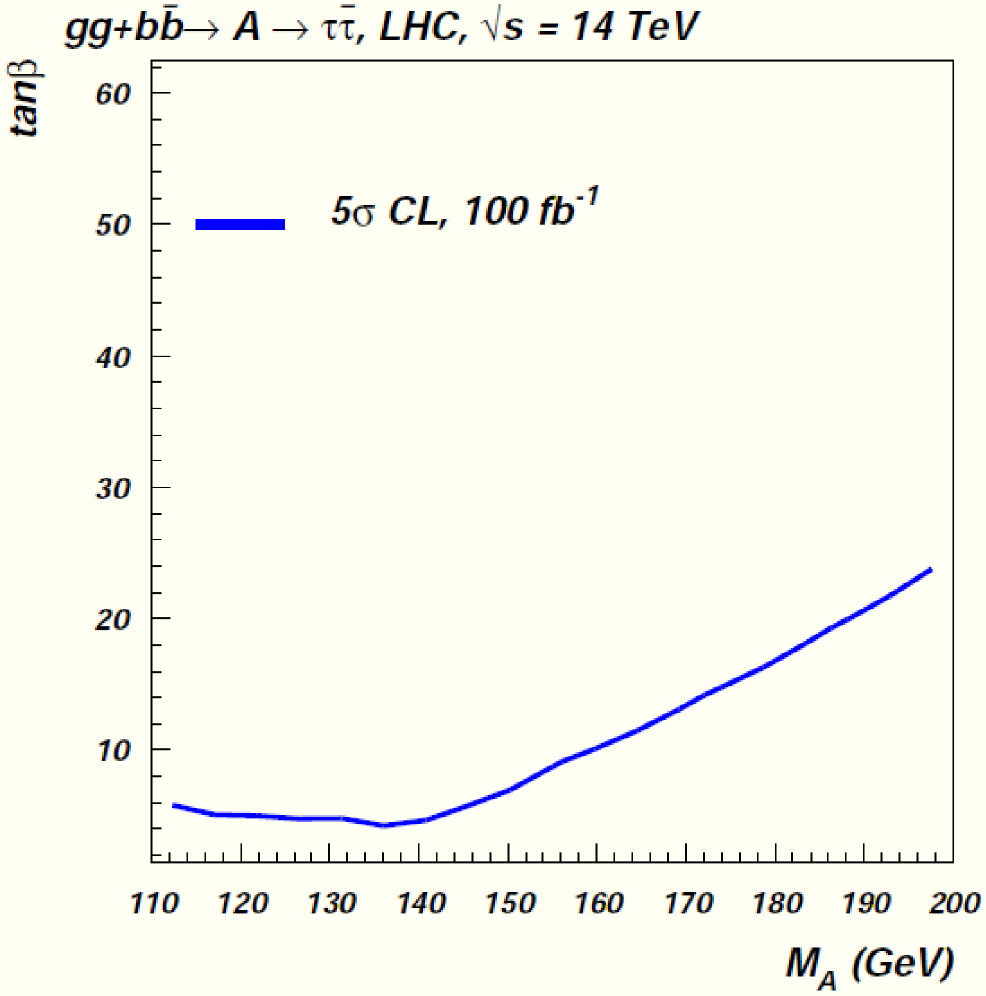


Visibility of MSSM Higgs bosons: $\tau\tau$ channel

Predicted LHC reach, based on the $h_{SM} \to \tau^+\tau^-$ studies

by D.Cavalli et al, hep-ph/0203056





What happens in alternative models of EWSB?

Technicolor

- Scalar states involved in EWSB are manifestly composite at scales not much above the electroweak scale $v \sim 250$ GeV
- A new asymptotically free strong gauge interaction, Technicolor, (Susskind,Weinberg) breaks the chiral symmetries of massless fermions
- additional light neutral pseudo Nambu-Goldstone bosons: “technipions” in Technicolor models

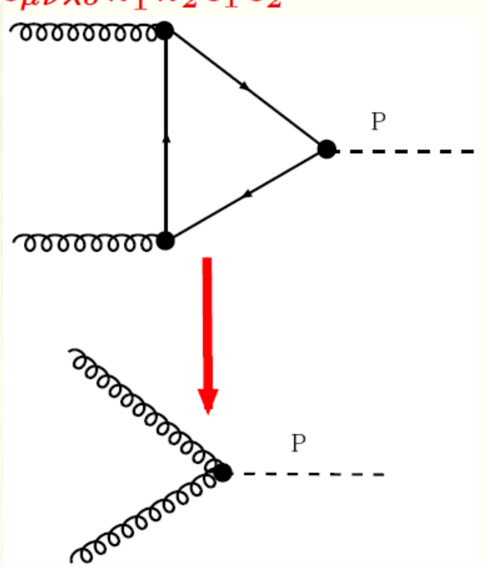
$N_{TC} \mathcal{A}_{V_1 V_2} \times \frac{g_1 g_2}{8\pi^2 F_P} \times \epsilon_{\mu\nu\lambda\sigma} k_1^\mu k_2^\nu \epsilon_1^\lambda \epsilon_2^\sigma$

$\Gamma(P \to gg) = \frac{m_P^3}{8\pi}\left(\frac{\alpha_s N_{TC} \mathcal{A}_{gg}}{2\pi F_P}\right)^2$, $m_P = 130$ GeV case

	1) one-family	2) variant one-family	3) multiscale	4) low-scale	
$\mathcal{A}_{gg}$	$\frac{1}{\sqrt{3}}$	$\frac{1}{\sqrt{6}}$	$\sqrt{2}$	$\frac{1}{\sqrt{3}}$	
$\mathcal{A}_{\gamma\gamma}$	$-\frac{4}{3\sqrt{3}}$	$\frac{16}{3\sqrt{6}}$	$\frac{4\sqrt{2}}{3}$	$\frac{34}{9}$	

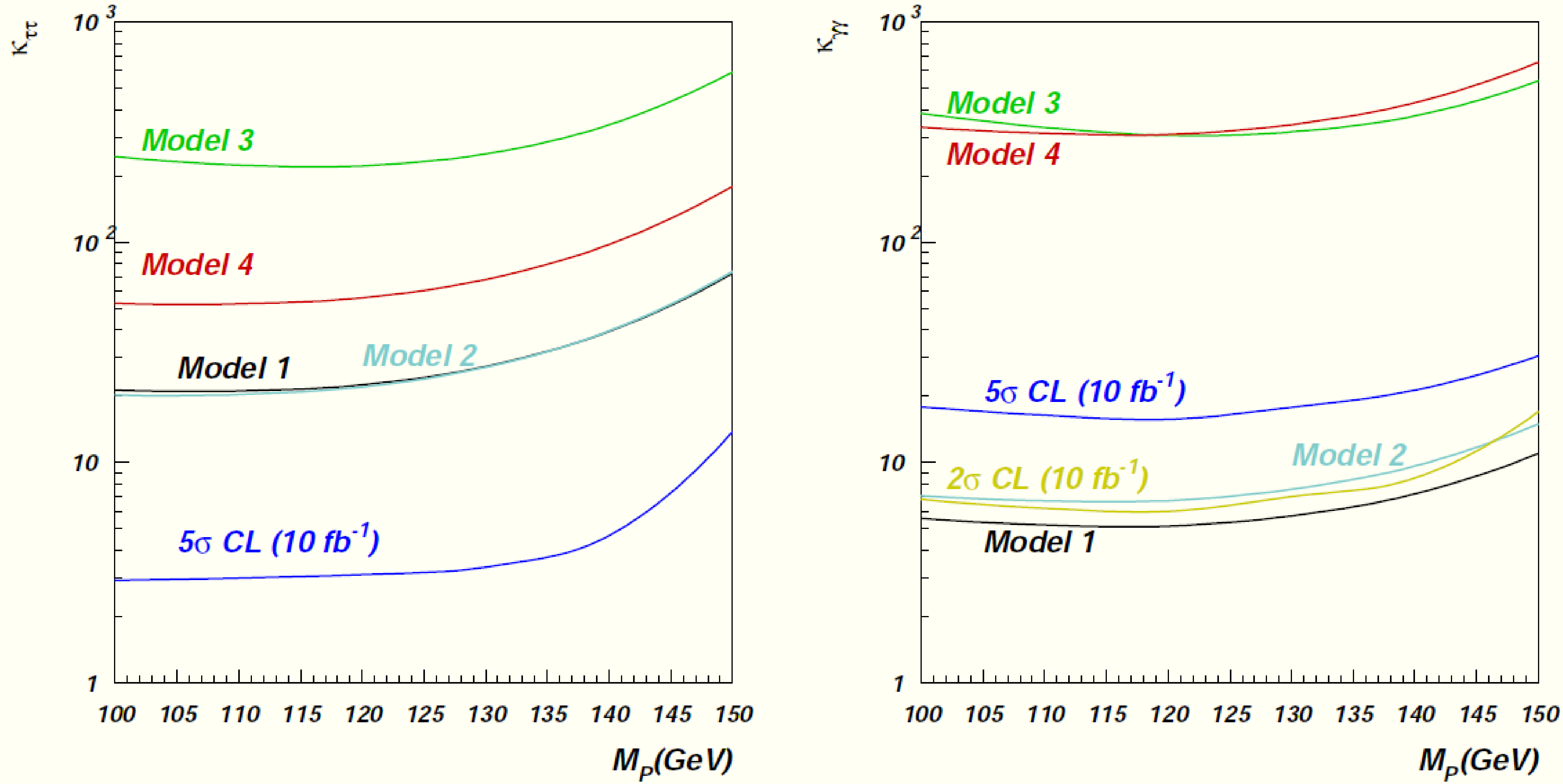
	1) one family	2) variant one-family	3) multiscale	4) low scale	
$\kappa^P_{gg\ prod}$	48	6	1200	120	
$\kappa^P_{bb\ prod}$	4	0.67	16	10	
κ^P_{prod}	47	5.9	1100	120	

$$F_P^{(1)} = \frac{v}{2},\quad F_P^{(2)} = v,\quad F_P^{(4)} = \frac{v}{\sqrt{10}},\quad F_P^{(3)} = \frac{v}{4}$$



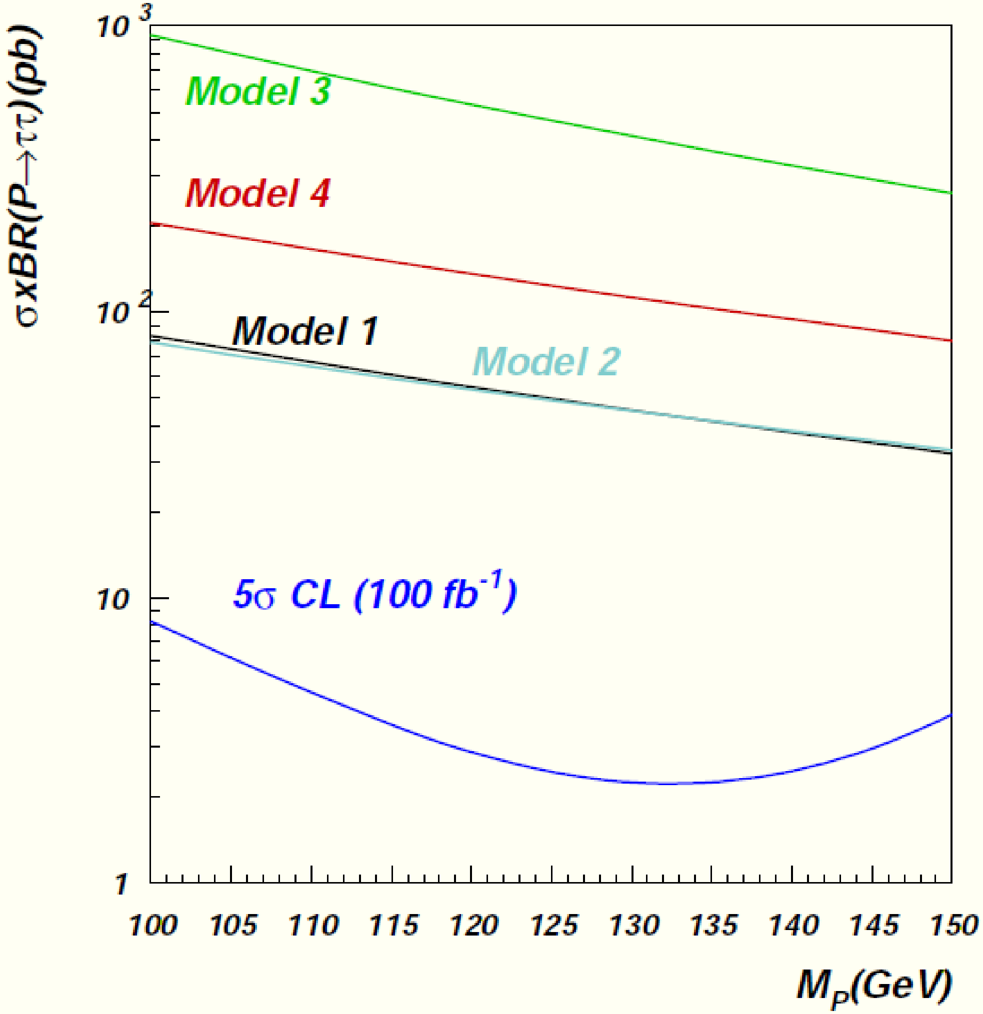
Visibility of Technipions: $\tau\tau$ and $\gamma\gamma$ channels

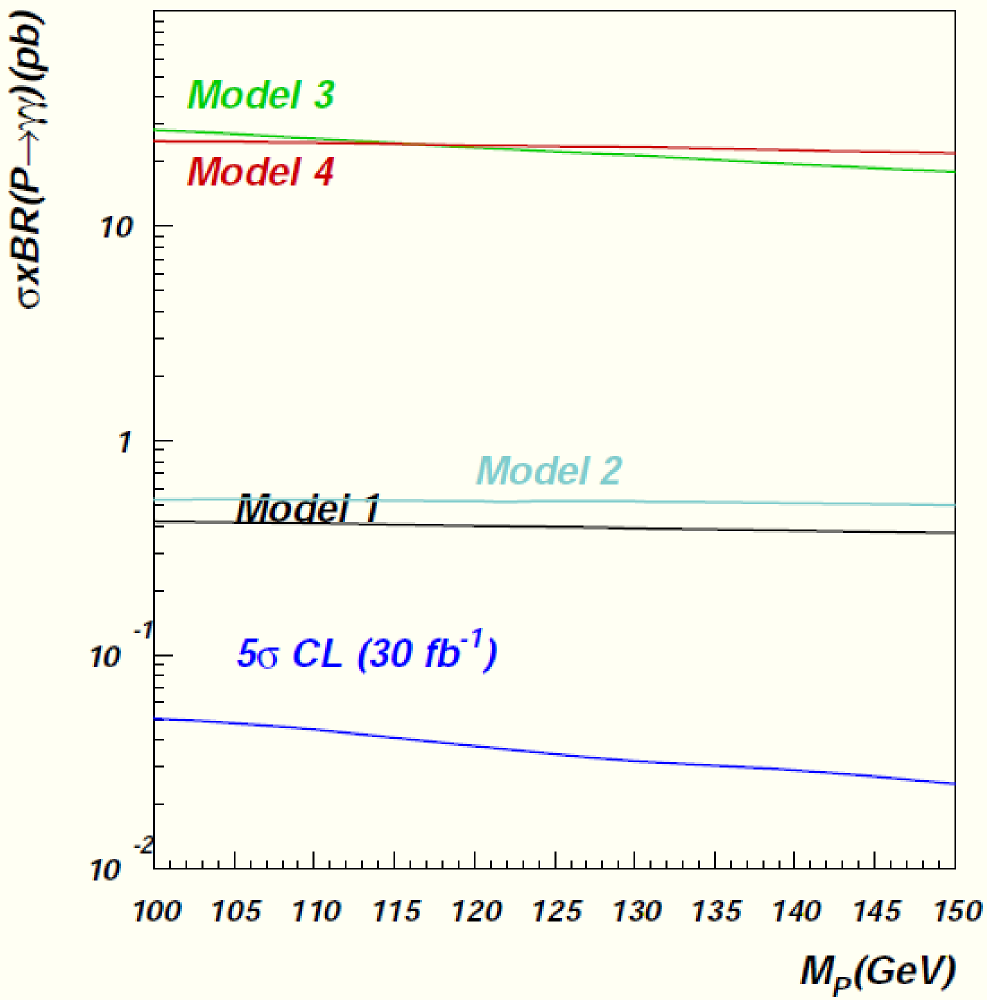
Predicted Tevatron reach, based on the $h_{SM} \to \tau^+\tau^-$ studies by A.B., T.Han, R.Rosenfeld, hep-ph/0204210 and on the $h_{SM} \to \gamma\gamma$ studies by S. Mrenna and J. D. Wells, hep-ph/0001226



Visibility of Technipions: $\tau\tau$ and $\gamma\gamma$ channels

Predicted LHC reach, based on the $h_{SM} \to \tau^+\tau^-$ studies by D.Cavalli et al, hep-ph/0203056 and on the $h_{SM} \to \gamma\gamma$ studies by R. Kinnunen, S. Lehti, A. Nikitenko and P. Salmi,hep-ph/0503067





Distinguishing SUSY from Technicolor models

- Tevatron and LHC have the potential to observe the light (pseudo) scalar states characteristic of both supersymmetry and models of dynamical symmetry breaking $\tau^+\tau^-$ channel!
- SUSY case: $\tau^+\tau^-$ channel is enhanced while the $\gamma\gamma$ channel is suppressed, and this suppression is strong enough that even the LHC would not observe the $\gamma\gamma$ signature.
- In contrast, for the dynamical symmetry breaking models studied we expect simultaneous enhancement of both the $\tau^+\tau^-$ and $\gamma\gamma$ channels.

Little Higgs Model as alternative to SUSY

Little Higgs scenario

New-Physics < 10TeV + EW ~ 0.1 TeV

Special arrangement for the cancellation of Λ^2 at 1-loop

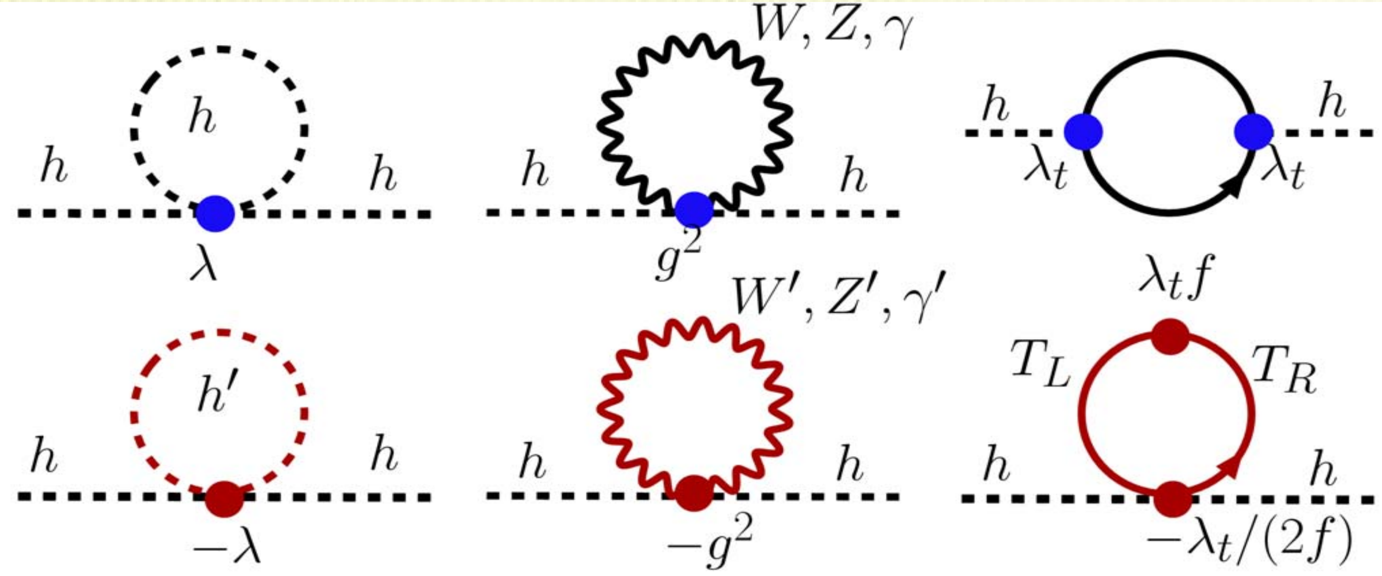
Littlest Higgs model

Arkani-Hamed, Cohen, Katz and Nelson (2002)

$SU(5) \supset [SU(2)\times U(1)]^2$ (gauged)

VEV = f ~ O(1) TeV

$SO(5) \supset SU(2)\times U(1)$ (diagonal)



New heavy particles **bosons, top-quarks, scalars** cancel the one-loop quadratic divergences

Little Higgs Model with T -parity

- Original LHM is suffered from severe constraints from EW observables. Tree-level corrections are due to the exchange of additional heavy gauge bosons and non-vanishing VEV of triplet higgs.
  f must be larger than 5 TeV, fine-tuning again !
- T-parity: Cheng, Low 2003, Z_2 symmetry

$$SU(2)_1 \times U(1)_1 \leftrightarrow SU(2)_2 \times U(1)_2$$

$$\text{SM particles} \quad \rightarrow \quad +\,\text{SM particles}$$

$$(W_H, Z_H, A_H, \Phi, Q) \rightarrow -(W_H, Z_H, A_H, \Phi, Q)$$

  - *No tree-level to EW observables*
  - *The lightest T-odd particle is a good DM candidate*
  - *New scale f can be lower then 1 TeV*

interesting phenomenology!

LHT Model

Hsin-Chia Cheng, Ian Low,

Jay Hubisz, Patrick Meade,

Andrew Noble, Maxim Perelstein,

Claudio O. Dib, Rogerio Rosenfeld,

Alfonso Zerwekh, Seung J. Lee, Gil Paz,

Chuan-Ren Chen, Kazuhiro Tobe,

C.-P. Yuan, Andreas Birkedal, ...

LHT Model is a good alternative, but

- Can LHT model phenomenology be distinguished from SUSY?
- The model can easily mimic SUSY signatures: cascade decays down to WIMP dark matter

The pattern of LHT Model

- Hiss boson is light – pseudo-Goldstone boson of SB global symmetry
- SM 1-loop quadratic divergences are canceled by new particles
- Z_2 symmetry relaxes EW constraints and provides DM

Vector bosons: $W_H^{\pm},\ Z_H,\ A_H$

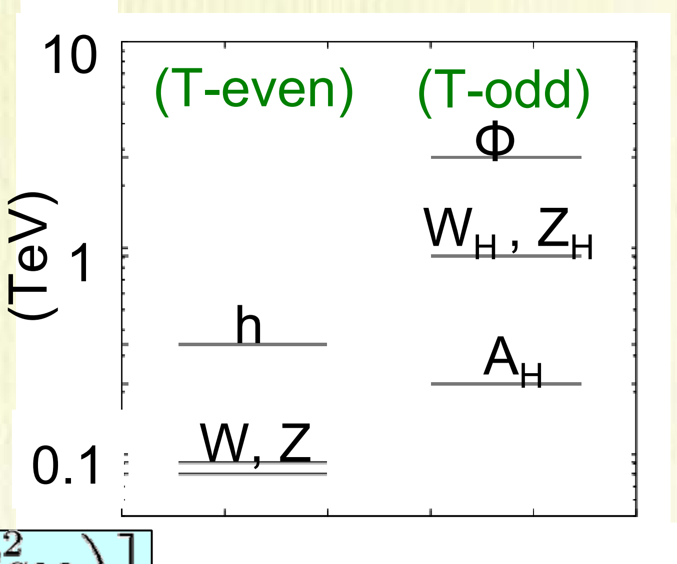
Fermions:

$SU(2)_L$ singlets – T_+, T_-

$SU(2)_L$ doublets – Q_L^-, L_L^-

Scalars: scalar $SU(2)_L$ triplet – $\phi^{\pm\pm},\ \phi^{\pm},\ \phi^0, \phi^P$

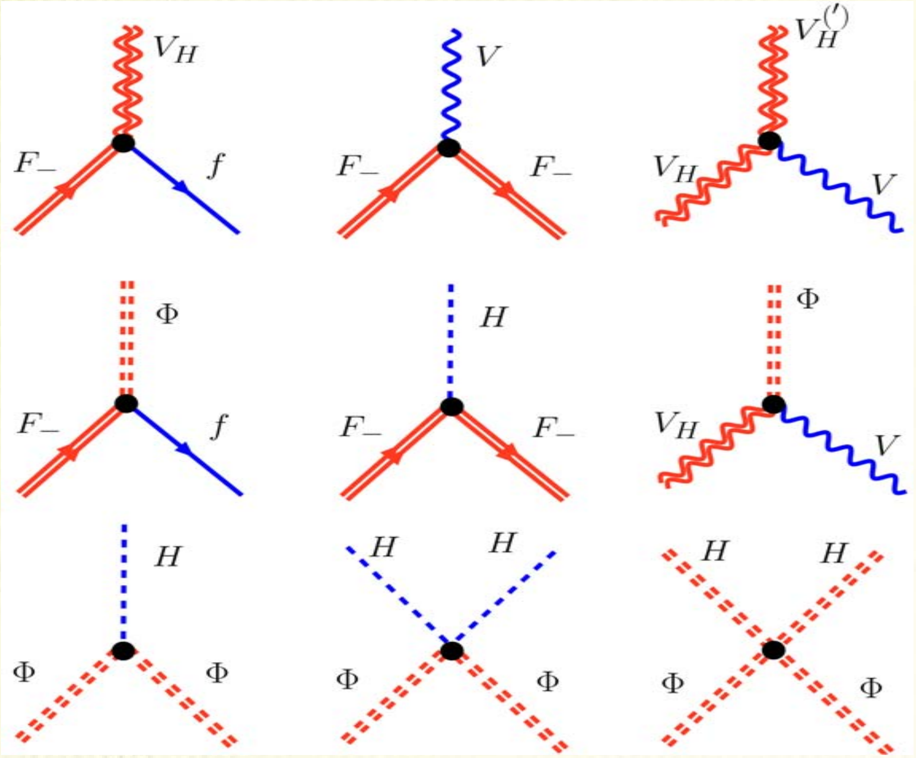
LHT Model



$$\sin\alpha = \lambda_1/\sqrt{\lambda_1^2+\lambda_2^2}$$
$$M_t \simeq (\lambda_2 \sin\alpha)v,$$
$$M_{t_-} \simeq \lambda_2 f, \quad M_{t_+} \simeq (\lambda_2/\cos\alpha)f$$
$$M_{Q_-} = \sqrt{2}\kappa f$$

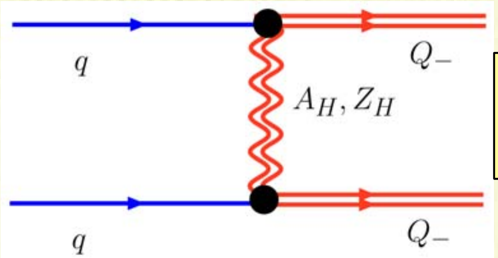
$$M_{A_H} = \frac{g' f}{\sqrt{5}}\left[1 + O\left(\frac{v_{SM}^2}{f^2}\right)\right], \; M_{Z_H} \simeq M_{W_H} = gf\left[1 + O\left(\frac{v_{SM}^2}{f^2}\right)\right]$$

- **Parameters and**
- **Interactions**

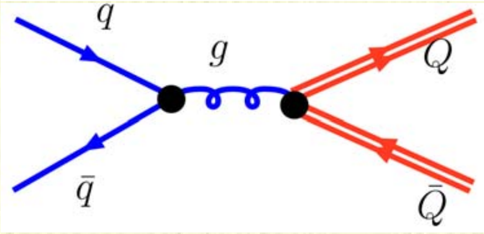


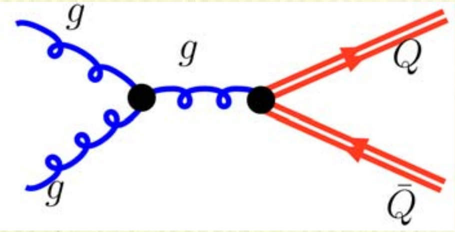
Phenomenology of LHT model

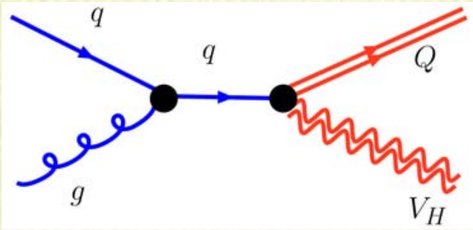
Promising Processes classification

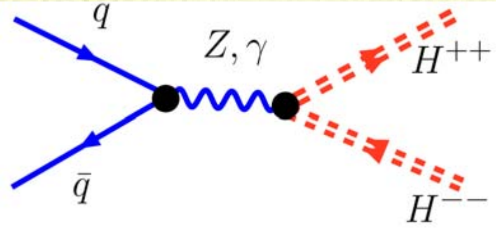


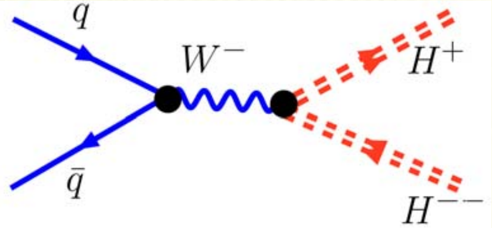
like-sign leptons!

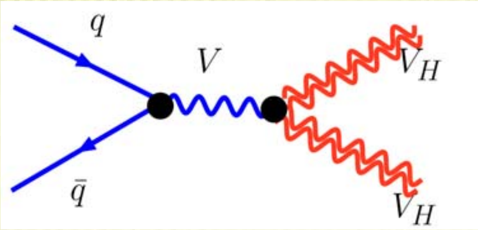


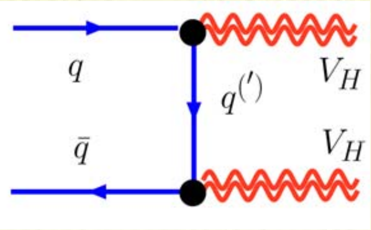






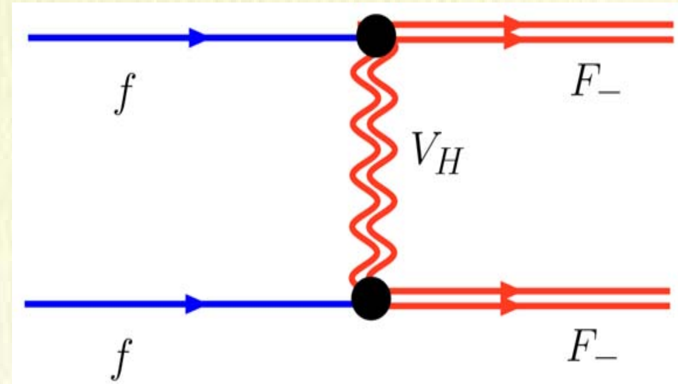


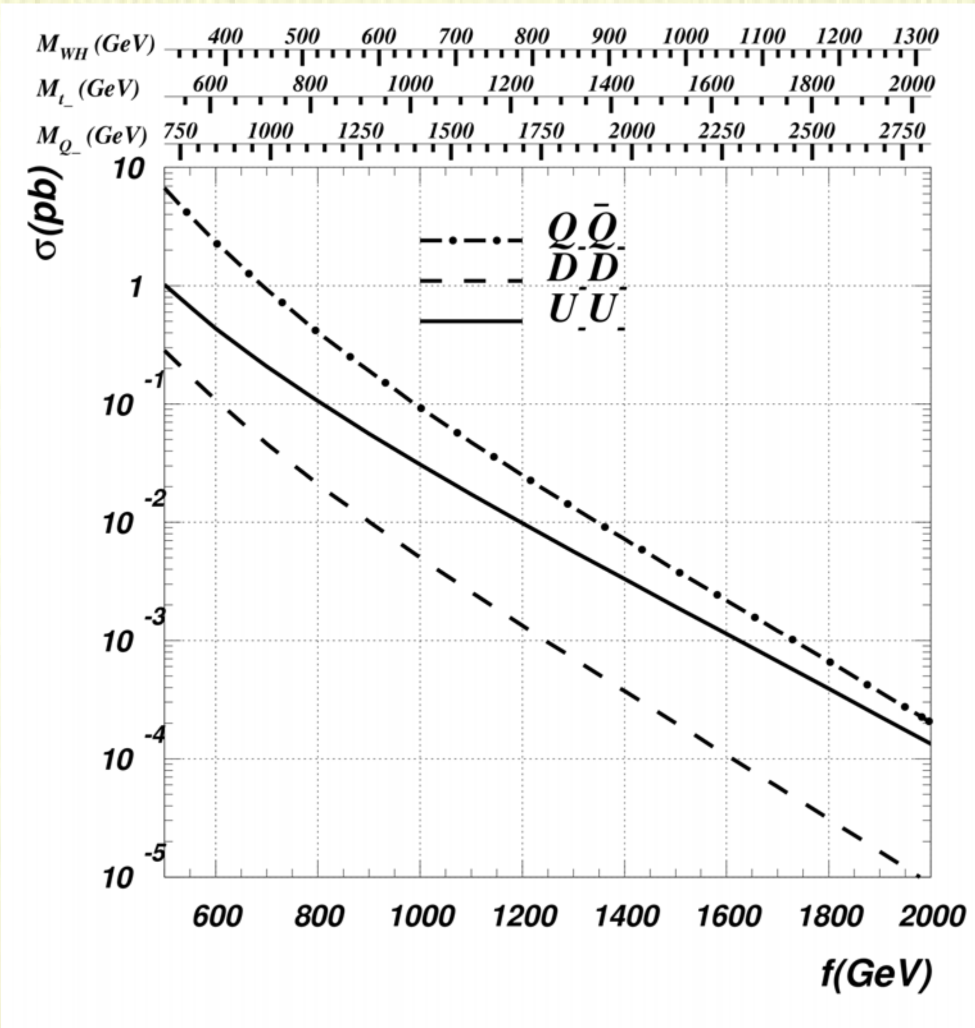




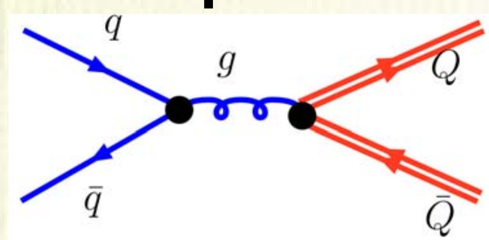
Heavy quarks production rates and signatures

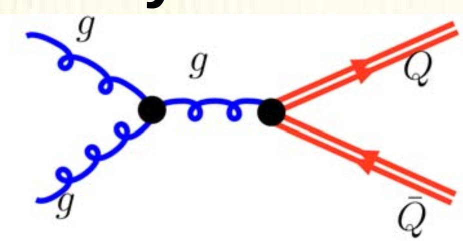
$$\sin\alpha = 1/\sqrt{2} \ \ (\lambda_1 = \lambda_2), \kappa = 1$$



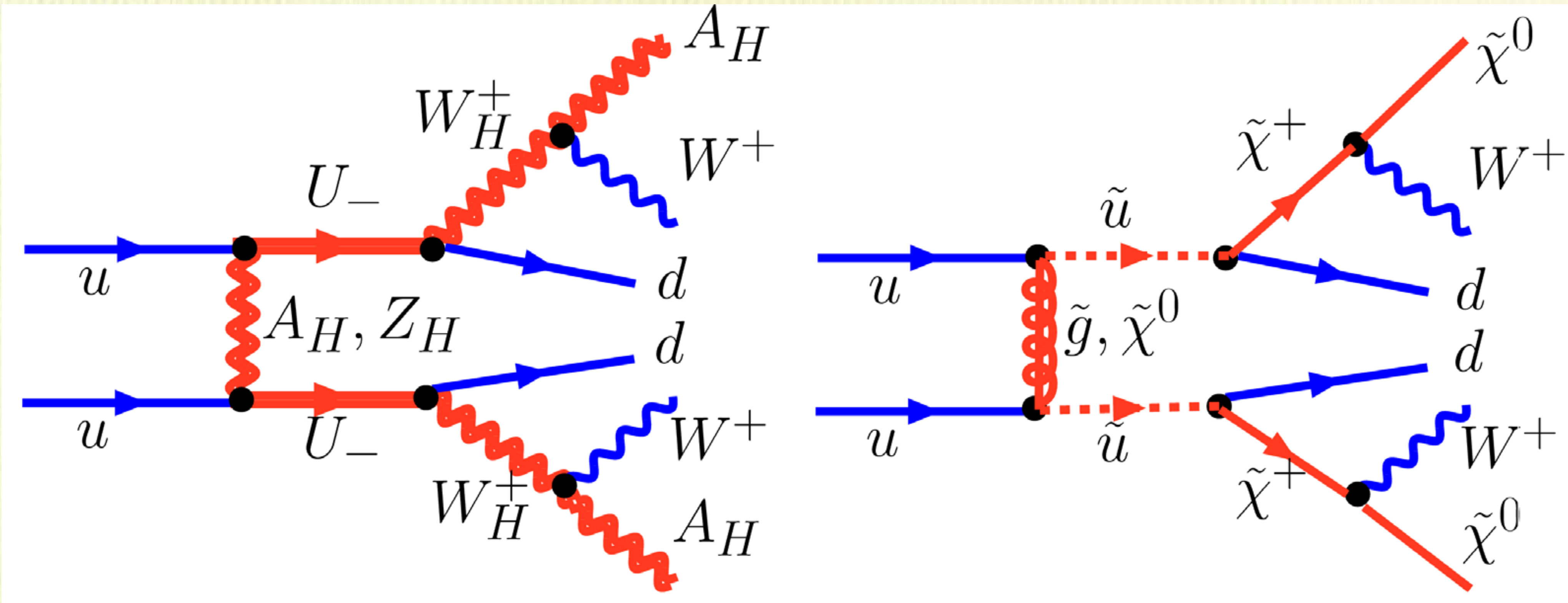


EW production due to the initial double valence quarks leads to like sign lepton signature (LSL), it is comparable to strong production and becomes even more important for heavier masses due to parton luminosity behavior!





LHT and SUSY cascade decays

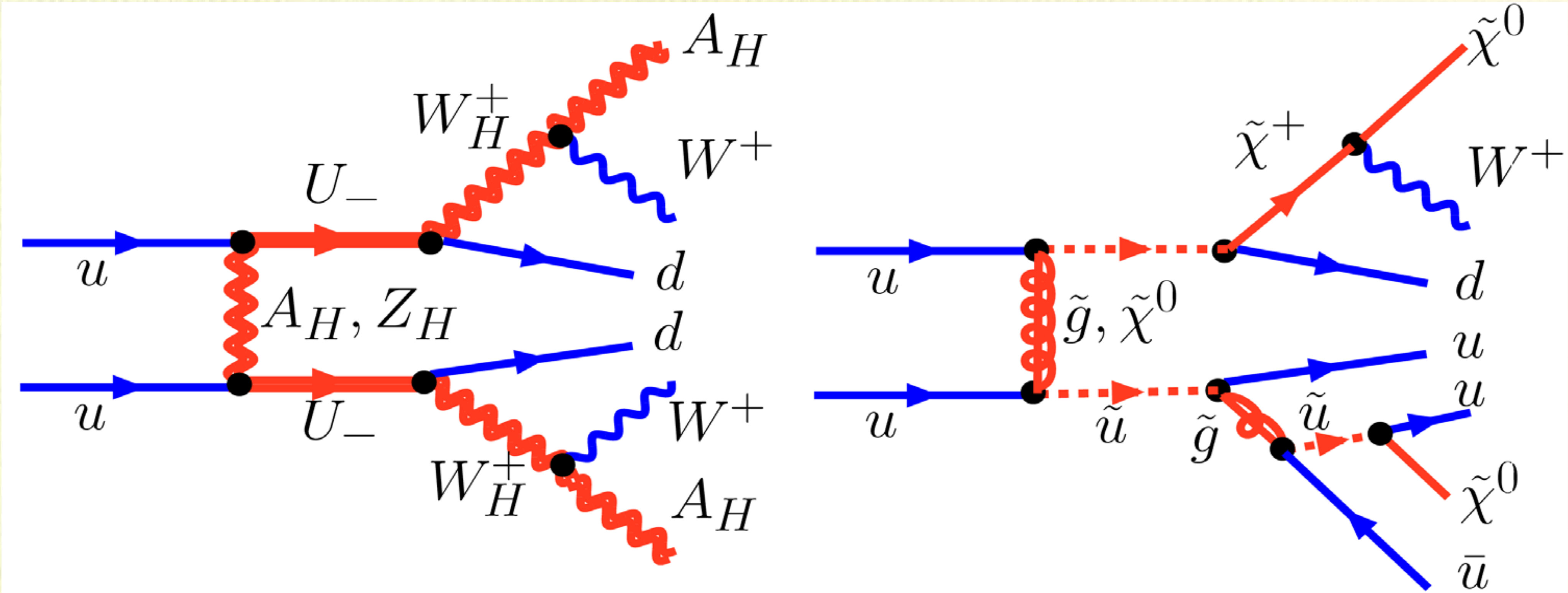


- **Both, SUSY and LHT give a very similar signature pattern**

$$\lambda_1 = \lambda_2 = 1$$
$$f = 1\ TeV, \quad \kappa = 1$$
$$Br(Q \to W_H q') = 0.62$$
$$Br(W_H \to W A_H) = 1$$

- **One should look closely: various decay channels, spin correlations, couplings**

LHT and SUSY cascade decays



- **Gluon has no partner in LHT model!**

$$\lambda_1 = \lambda_2 = 1$$
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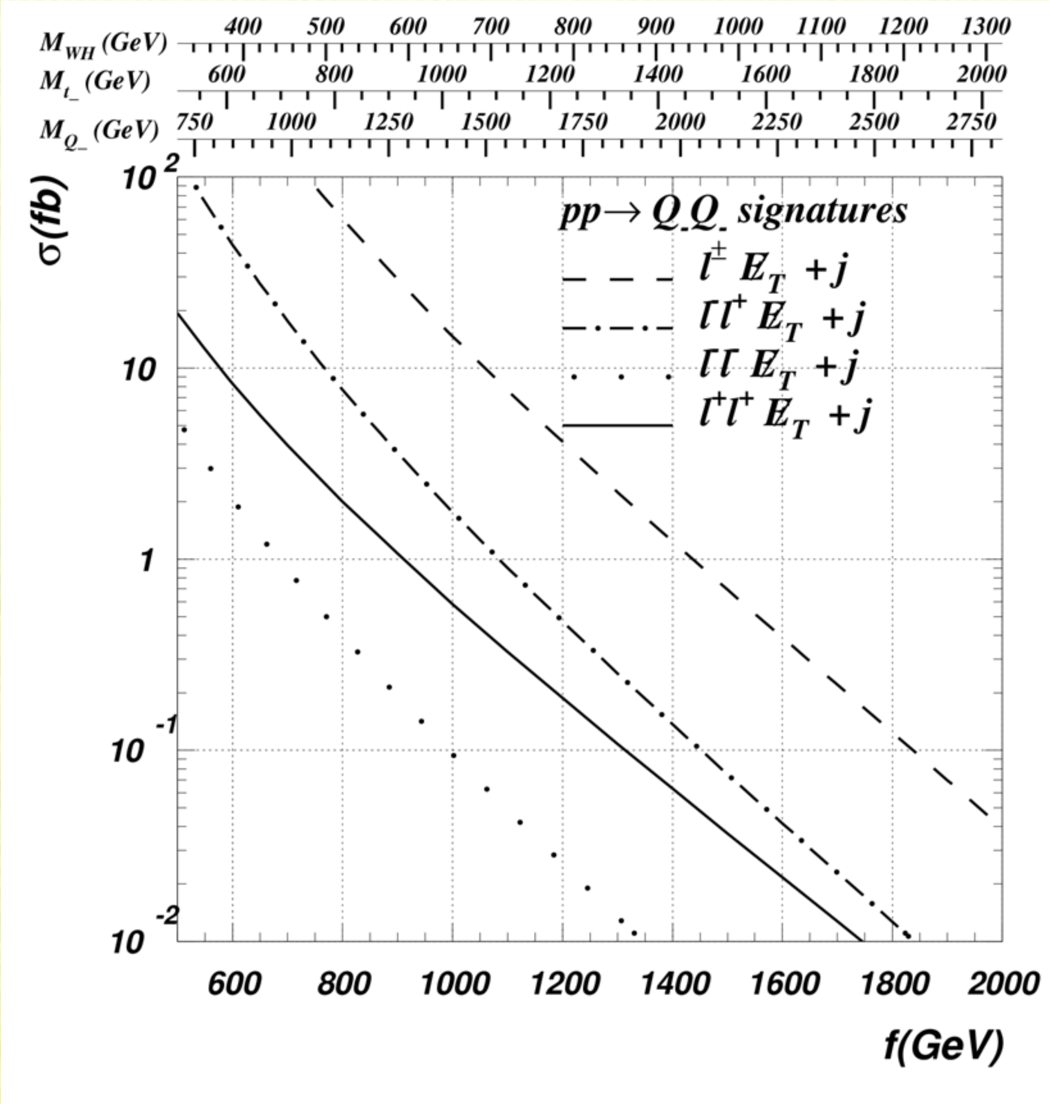
- **Study of spins and couplings is quite a challenge at the LHC**

Heavy quarks production rates and signatures



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Like-sign lepton signature (LSL)

$$qq \to QQ$$
$$(Q \to W_H^+ q') \to W_H^+ W_H^+ q' q'$$

Opposite sign lepton signature and 1-lepton signature (1L)

$$q\bar{q}(gg) \to Q\bar{Q} \to W_H^+ W_H^- q' \bar{q}'$$

Conclusions

- Understanding the Underlying Model can be a serious problem since SUSY alternatives having partial SUSY properties lead to a very similar signatures
- To discriminate underlying theory (not just SUSY!) one should actually perform
  studies opposite to inverse problem –
  we should understand the signal pattern for specific models to identify them in the end!
- Study of fine effects such as spin and couplings of new particles is necessary.
  This task might be problematic at the LHC. If this is the case, then ILC would be precious but important tool to accomplish it.
- Lets keep up our efforts!

Technicolor enhancement factor for production and decay

$$\Gamma(P \to gg) = \frac{m_P^3}{8\pi}\left(\frac{\alpha_s N_{TC} \mathcal{A}_{gg}}{2\pi F_P}\right)^2, m_P = 130 \text{ GeV case}$$

	1) one-family	2) variant one-family	3) multiscale	4) low-scale	
$\mathcal{A}_{gg}$	$\frac{1}{\sqrt{3}}$	$\frac{1}{\sqrt{6}}$	$\sqrt{2}$	$\frac{1}{\sqrt{3}}$	
$\mathcal{A}_{\gamma\gamma}$	$-\frac{4}{3\sqrt{3}}$	$\frac{16}{3\sqrt{6}}$	$\frac{4\sqrt{2}}{3}$	$\frac{34}{9}$	

	1) one family	2) variant one-family	3) multiscale	4) low scale	
$\kappa^P_{gg\ prod}$	48	6	1200	120	
$\kappa^P_{bb\ prod}$	4	0.67	16	10	
κ^P_{prod}	47	5.9	1100	120	

Decay Channel	1) one family	2) variant one family	3) multiscale	4) low scale	SM Higgs
$b\bar{b}$	0.60	0.53	0.23	0.60	0.53
$c\bar{c}$	0.05	0	0.03	0.05	0.02
$\tau^+\tau^-$	0.03	0.25	0.01	0.03	0.05
gg	0.32	0.21	0.73	0.32	0.07
$\gamma\gamma$	2.7×10^{-4}	2.9×10^{-3}	6.1×10^{-4}	6.4×10^{-3}	2.2×10^{-3}
W^+W^-	0	0	0	0	0.29