

# Early LHC Data & New Physics?

( $\approx$  summary of the LHC2FC CERN TH Institute)

LCWS, Beijing, March 28, 2010



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23:59 March 29, 2010... waiting for collisions



23:59 March 29, 2010... waiting for collisions



the LHC results will set the agenda for future colliders

# Early LHC data: shaping the future of HEP

- ⦿ Results from the LHC will drastically improve our knowledge of TeV scale physics
- ⦿ Complexity and size of possible future accelerator experiments
  - ⇒ need to plan ahead for future programme
- ⦿ LC status so far : there is a strong physics case for a 500 GeV LC as the next step beyond the LHC, even before we know what the LHC will tell us (consensus documents, . . . )
- ⦿ Early LHC data
  - ⇒ shape the future of particle physics
  - ⇒ We will need to reassess our future options in the light of results of the LHC and the Tevatron

G. Weiglein, Tsukuba, 2009

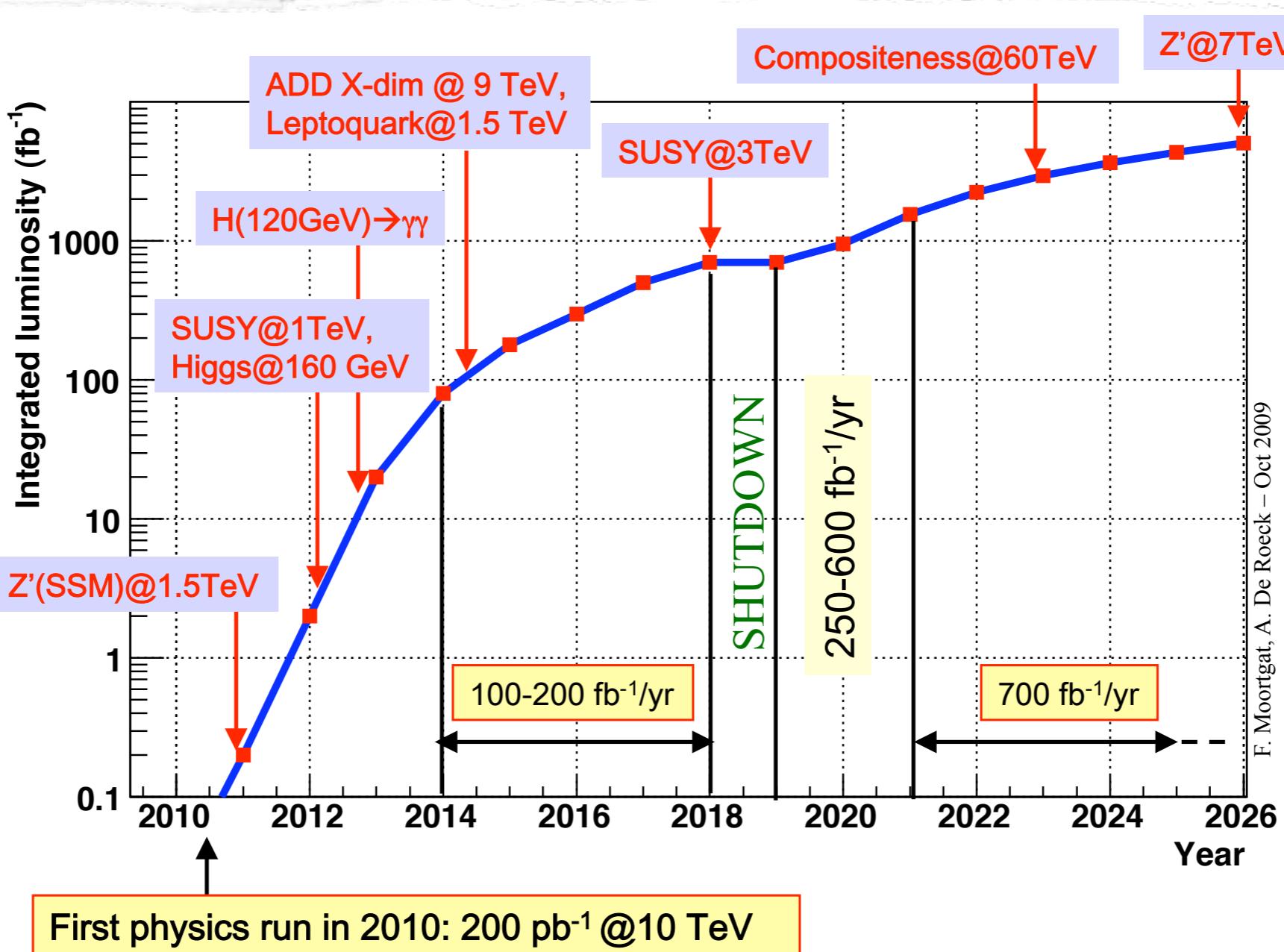
# Early LHC data: a possible window of opportunity

- ⦿ Exciting results from the early LHC data could open up a window of opportunity for securing a long-term future of the field: possibility to bring a new major facility on the way
- ⦿ The particle physics community will have to act quickly and speak with a unanimous voice:
  - ⇒ We will need to come up with a convincing and scientifically solid conclusion on how to proceed
  - ⇒ It is useful to discuss possible ways ahead already before the first LHC data become available

G. Weiglein, Tsukuba, 2009

# Which early data for which physics?

$LHC_{10} = LHC_{2010}?$ ,  $LHC_{10\text{TeV}, 10/\text{fb}}$ ?



# $Z'$ timeline

Salvioni, Villadoro, Zwirner '09

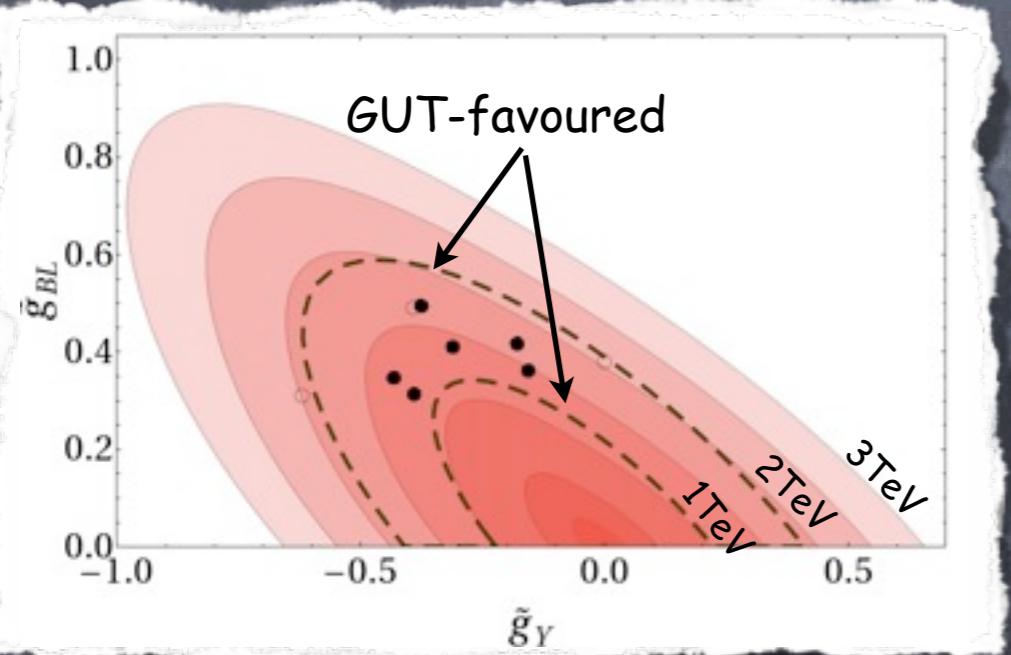
"How bounds from existing experiments affect the discovery reach  
in the very early phase of the LHC?"

flavour universal anomaly-free  $Z'$ : 3 parameters ( $M_{Z'}$ ,  $g_Y$ ,  $g_{BL}$ )

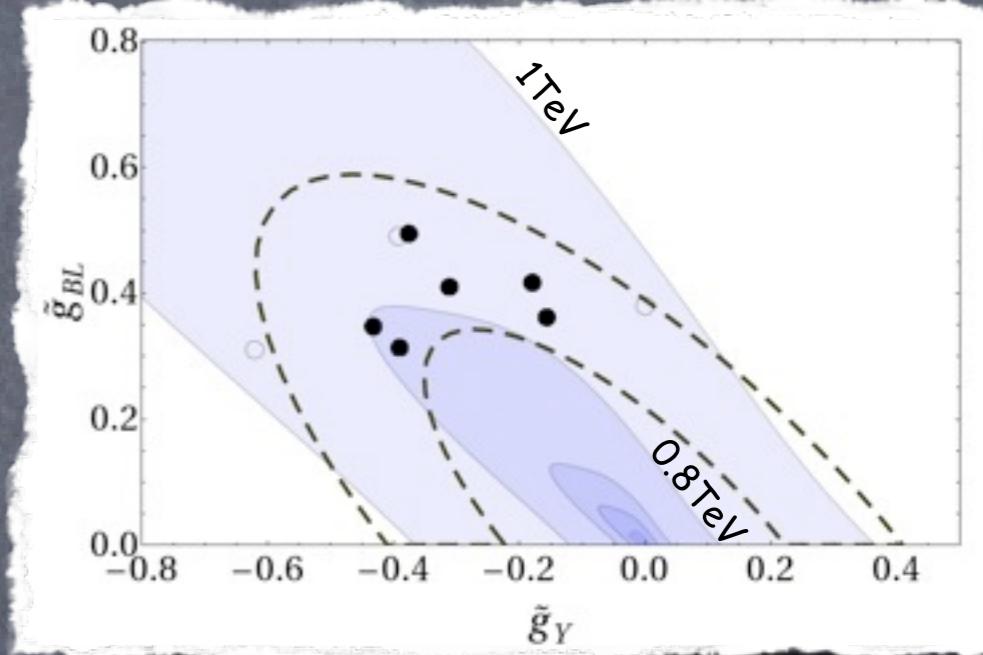
EPWT

constraints from

Tevatron searches



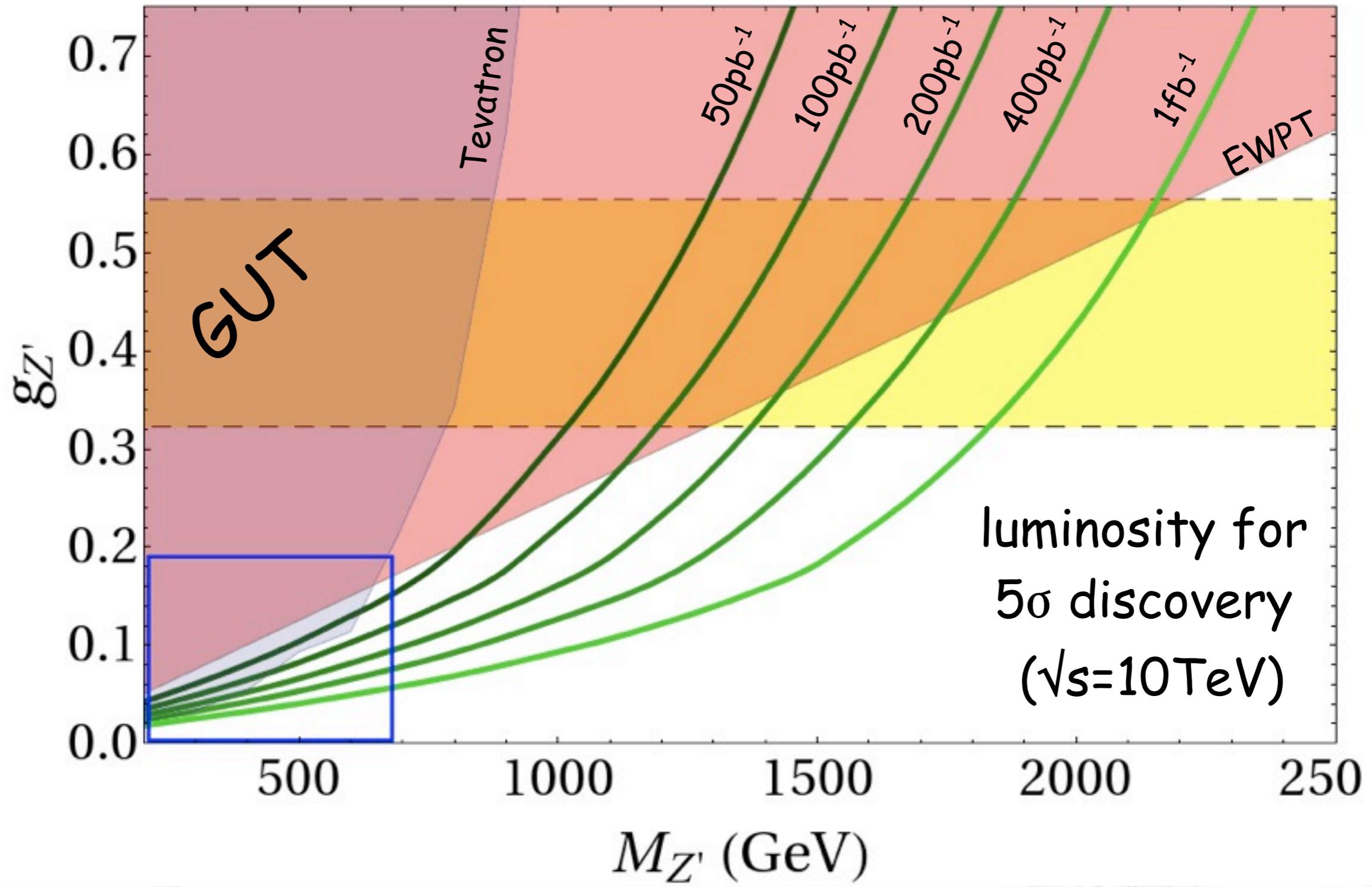
more stringent for heavy  $Z'$



more stringent for light  $Z'$

# Z' timeline

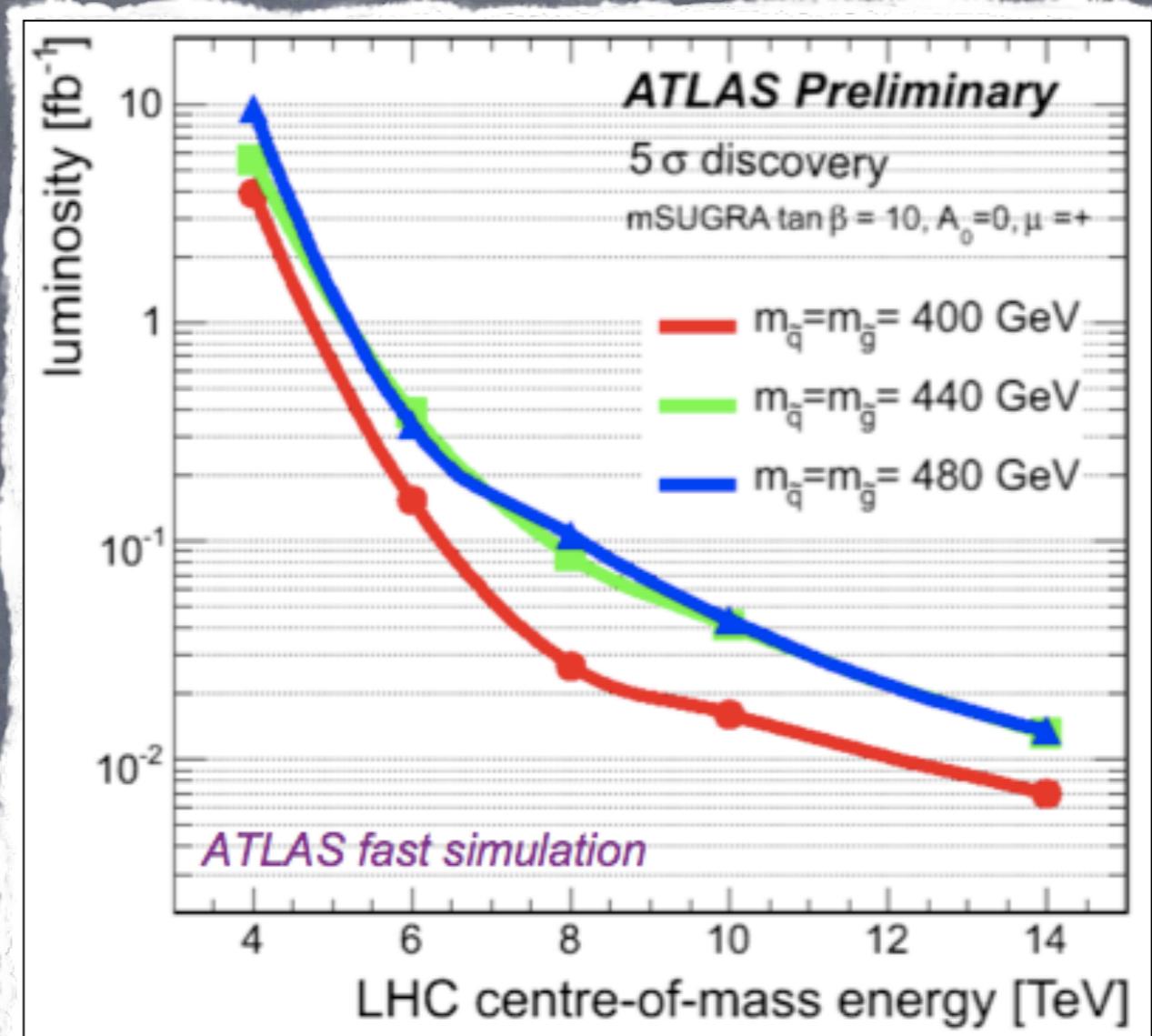
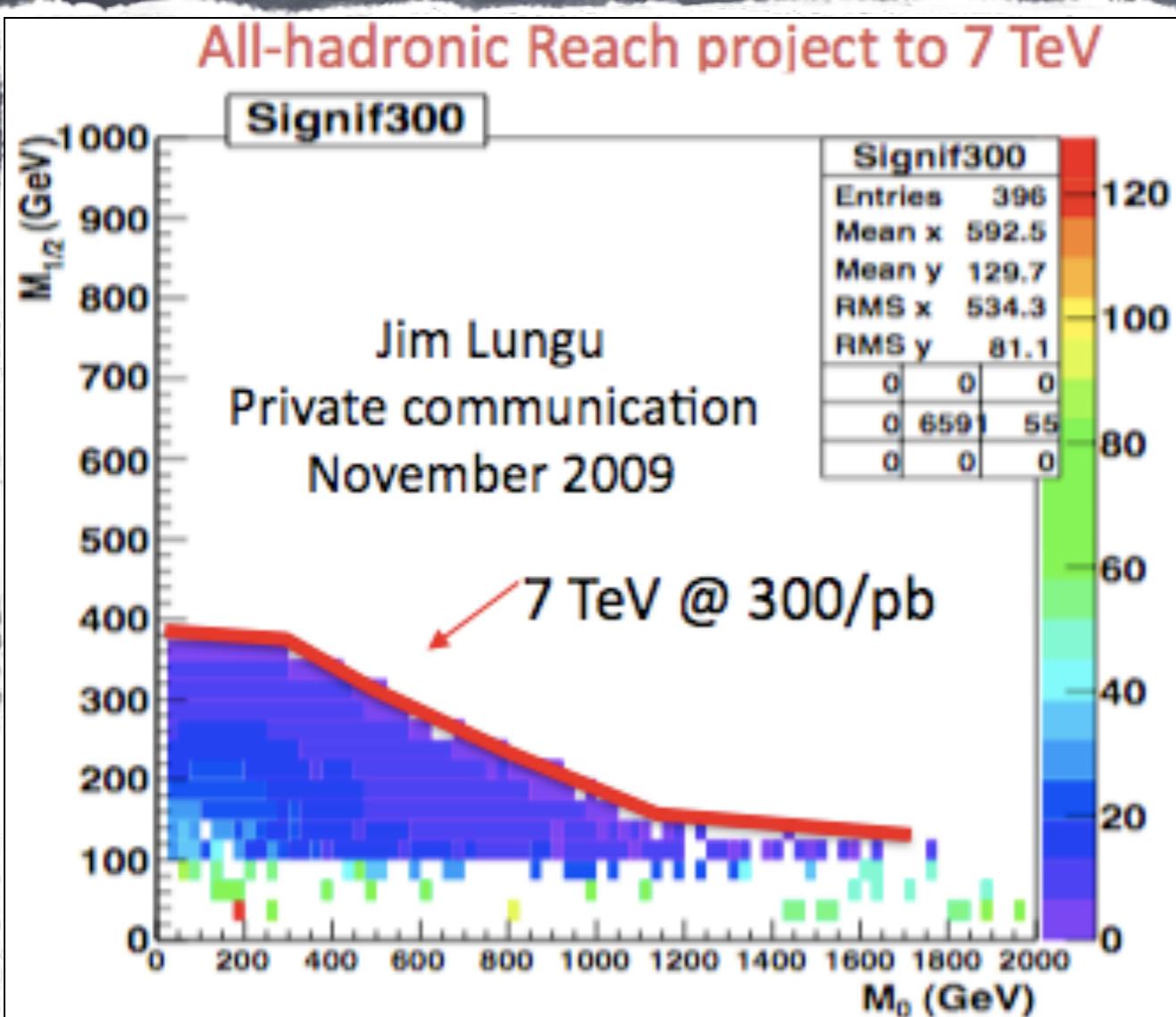
Salvioni, Villadoro, Zwirner '09



GUT-like Z' discovery requires 'large' luminosity & energy

# SUSY timeline

J. Ellis @ Strings 2010



Discovering light SUSY at early LHC is still possible

# SUSY little hierarchy pb

SUSY need new (super)particles that haven't been seen yet  
SUSY (at least MSSM) predicts a very light Higgs



## Tree-level

$$V = (|\mu|^2 + m_{H_u}^2) |H_u^0|^2 + (|\mu|^2 + m_{H_d}^2) |H_d^0|^2 - B(H_u^0 H_d^0 + c.c.) + \frac{g^2 + g'^2}{8} \left( |H_u^0|^2 - |H_d^0|^2 \right)^2$$

tree-level

$$m_h^2 = m_Z^2 \cos^2 2\beta$$

$$m_Z^2/2 = -\mu^2 + \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2 \beta}{\tan^2 \beta - 1}$$

excluded



## Loop-level

one-loop level

$$m_h^2 \approx m_Z^2 \cos^2 2\beta + \frac{3G_F m_t^4}{\sqrt{2}\pi^2} \log \frac{m_{\tilde{t}}^2}{m_t^2}$$

$$m_H > 115 \text{ GeV} \Leftrightarrow m_{\tilde{t}} > 1 \text{ TeV}$$

$$\delta m_{H_u}^2 = -\frac{3\sqrt{2}G_F m_t^2 m_{\tilde{t}}^2}{4\pi^2} \log \frac{\Lambda}{m_{\tilde{t}}}$$

$$m_Z^2/2 = -\mu^2 + \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2 \beta}{\tan^2 \beta - 1}$$

requires some fine-tuning  $O(1\%)$  in  $m_Z$

fine-tuned

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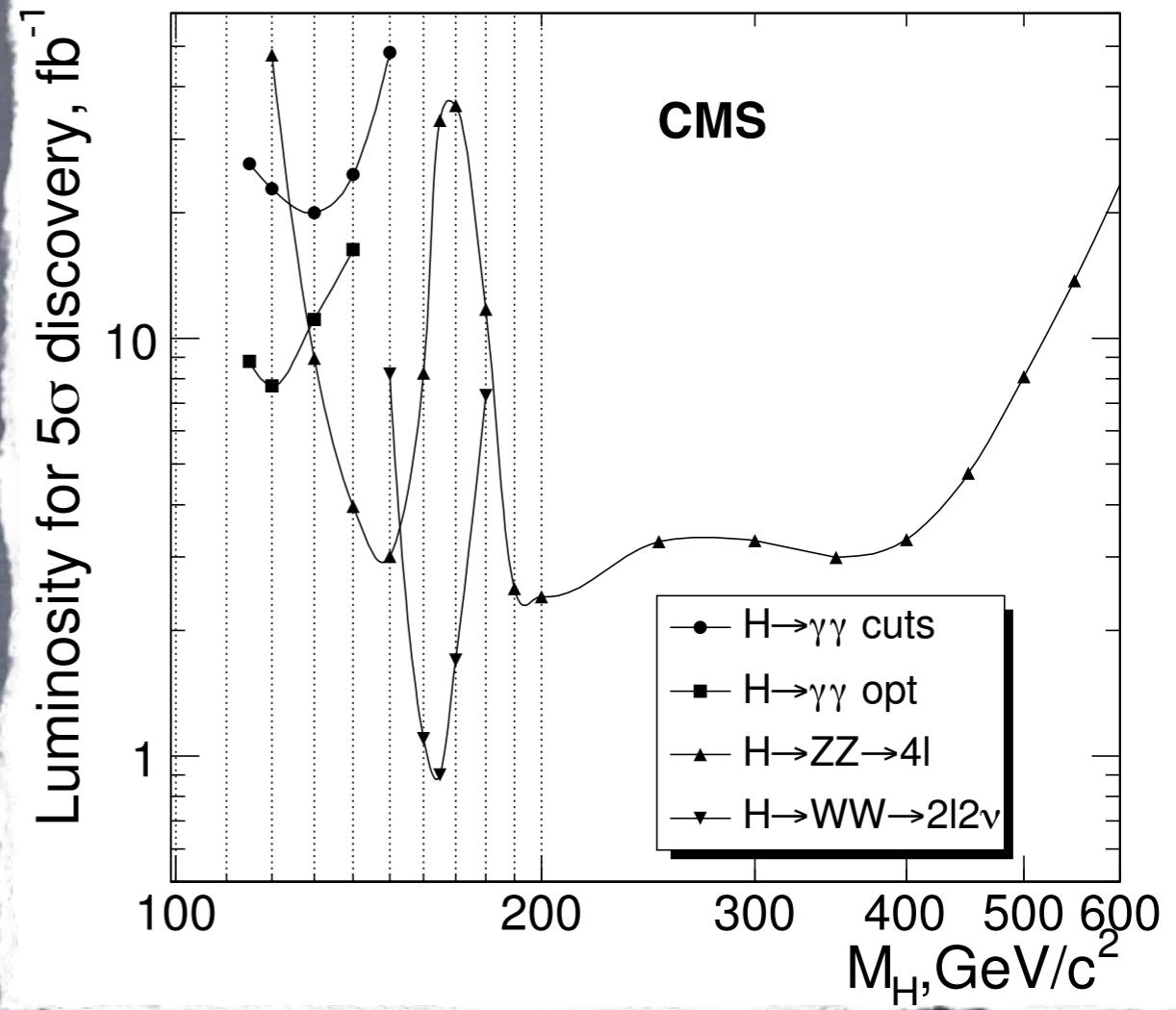
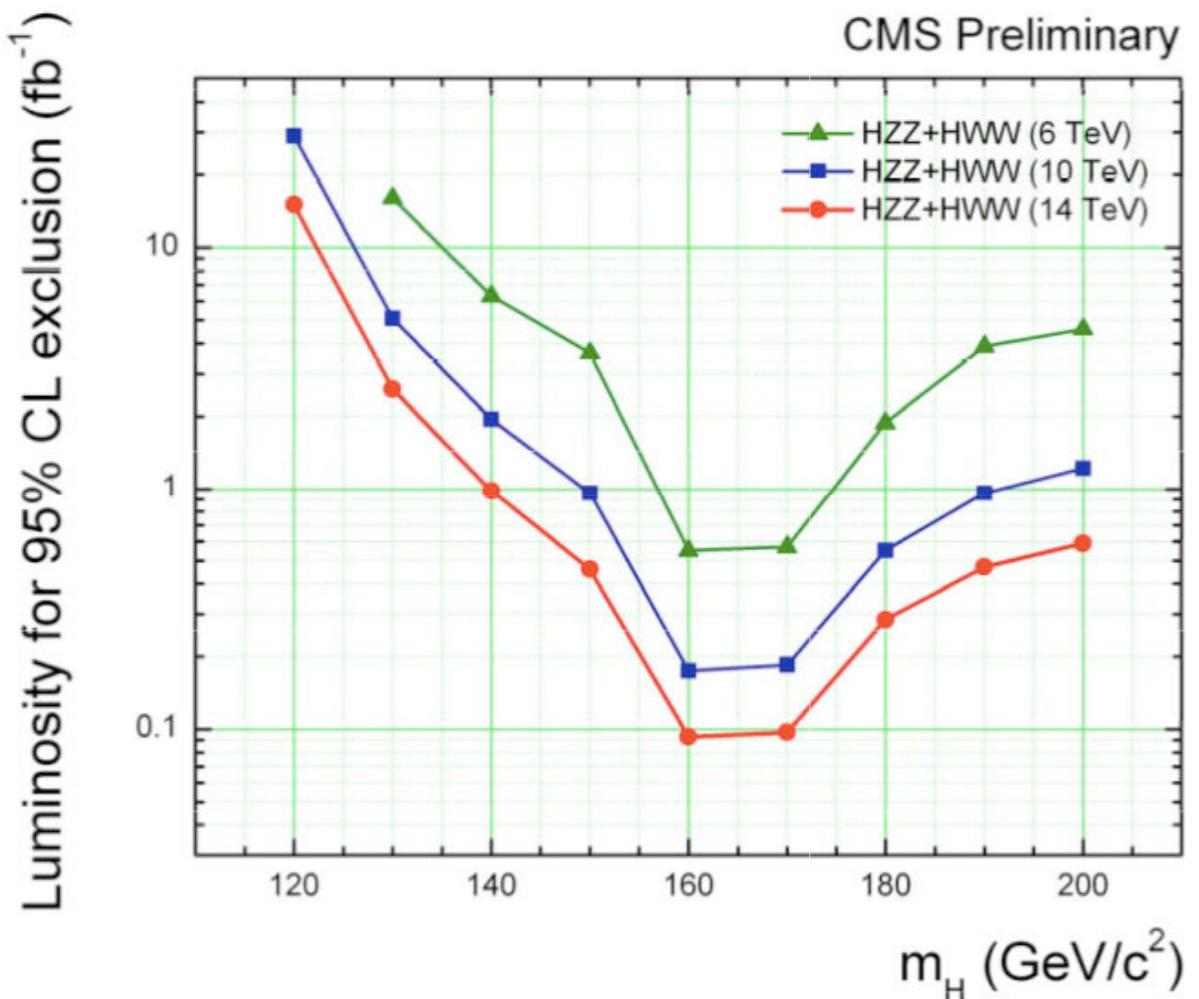
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requires some fine-tuning  $O(1\%)$  in  $m_Z$

fine-tuned

SUSY benchmark points accessible at early LHC are either fine-tuned or required a yet unknown dynamics

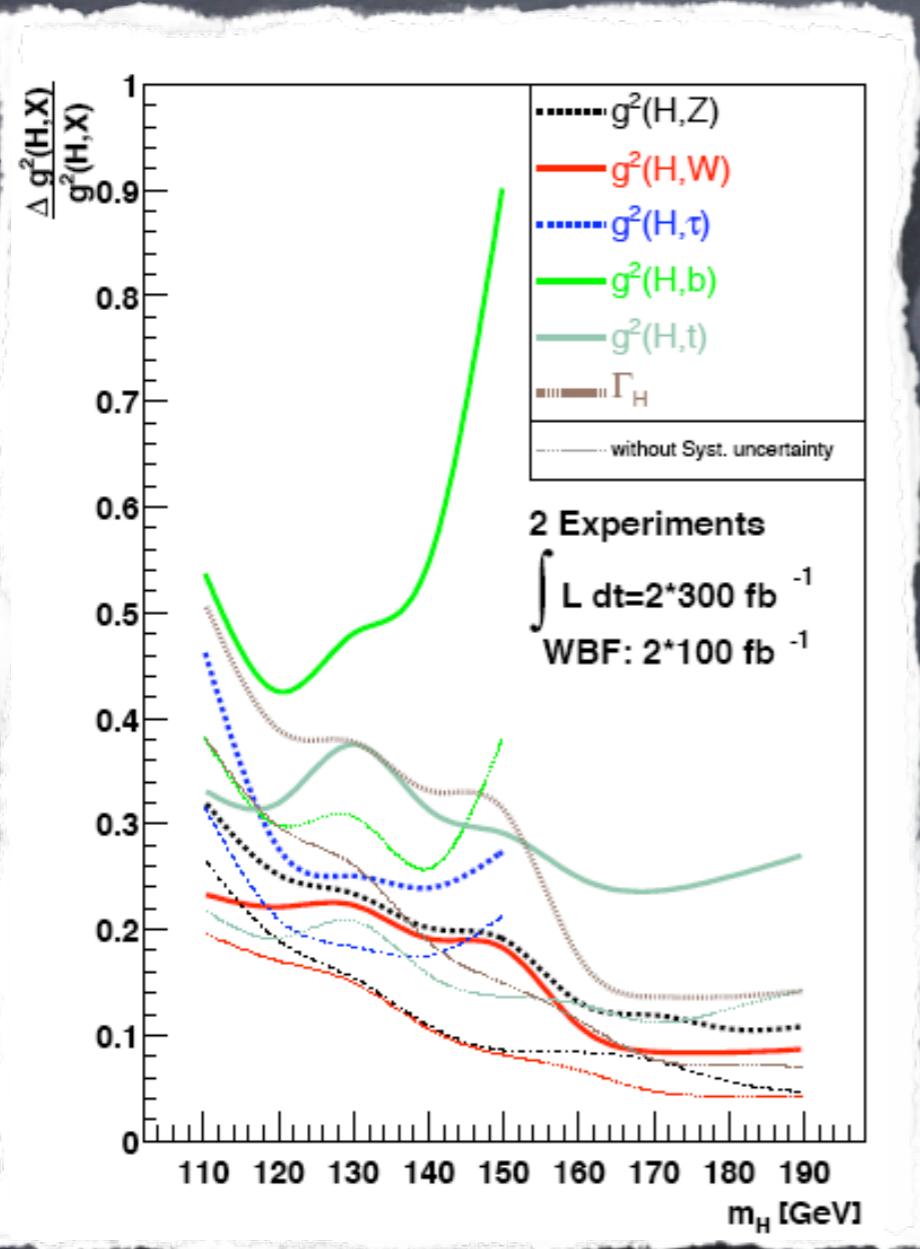
# Higgs timeline



## Benchmark luminosities

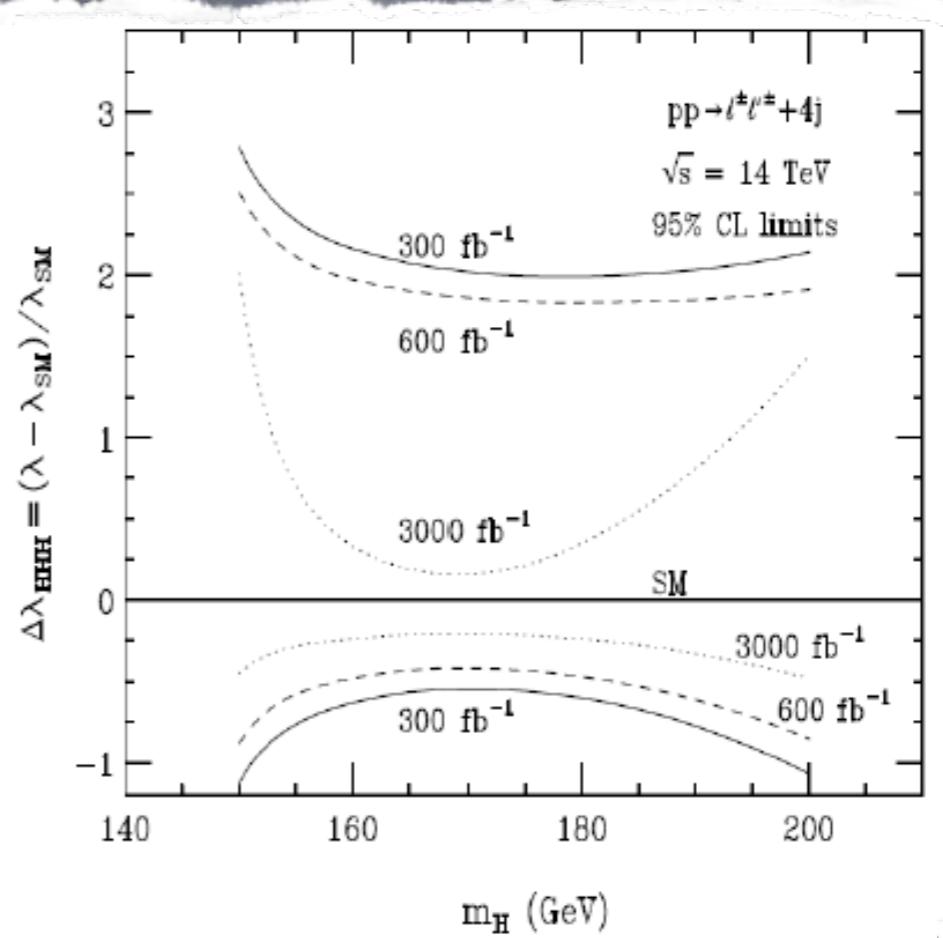
- $0.1 \text{ fb}^{-1}$ : exclusion limits start carving into SM Higgs cross sections
- $1 \text{ fb}^{-1}$ : discoveries become possible if  $m_H \sim 160-170 \text{ GeV}$
- $10 \text{ fb}^{-1}$ : SM Higgs discovered or excluded

# Higgs timeline



Higgs couplings

not early physics!



Higgs self-couplings

# Higgs: elementary vs. composite

**SM Higgs**

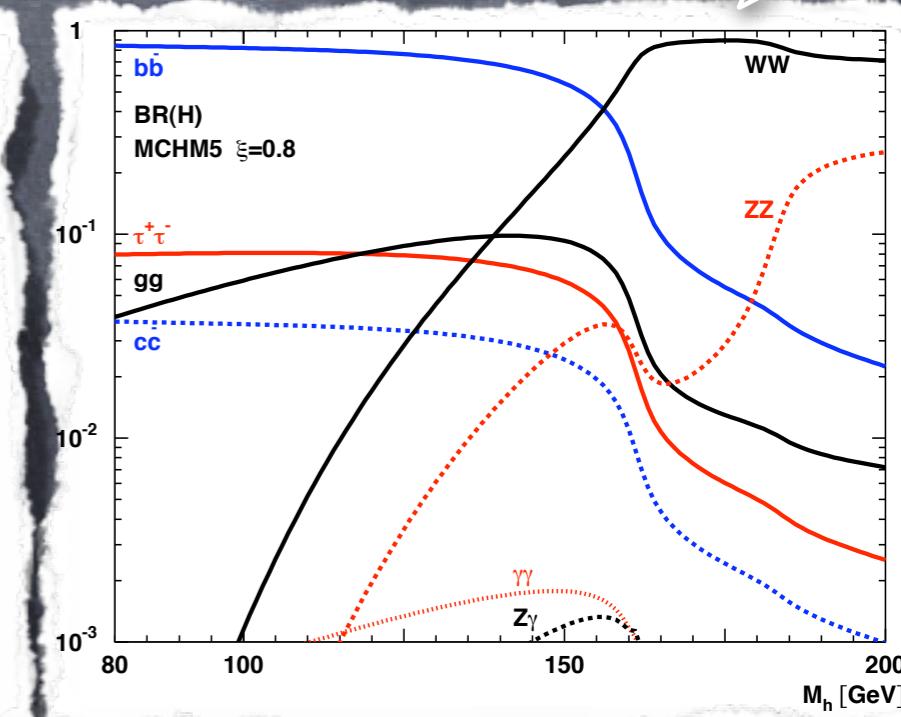
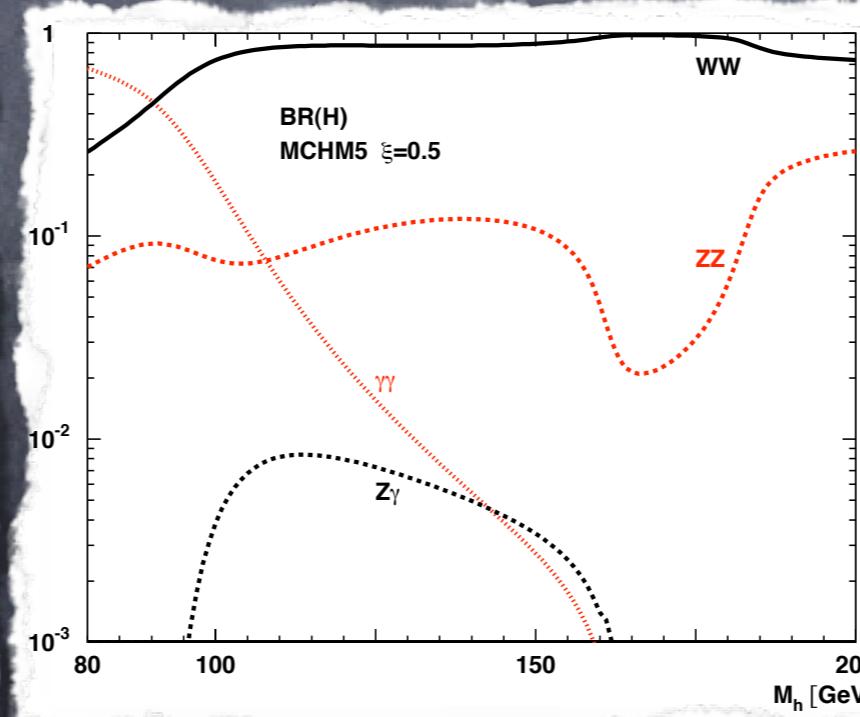
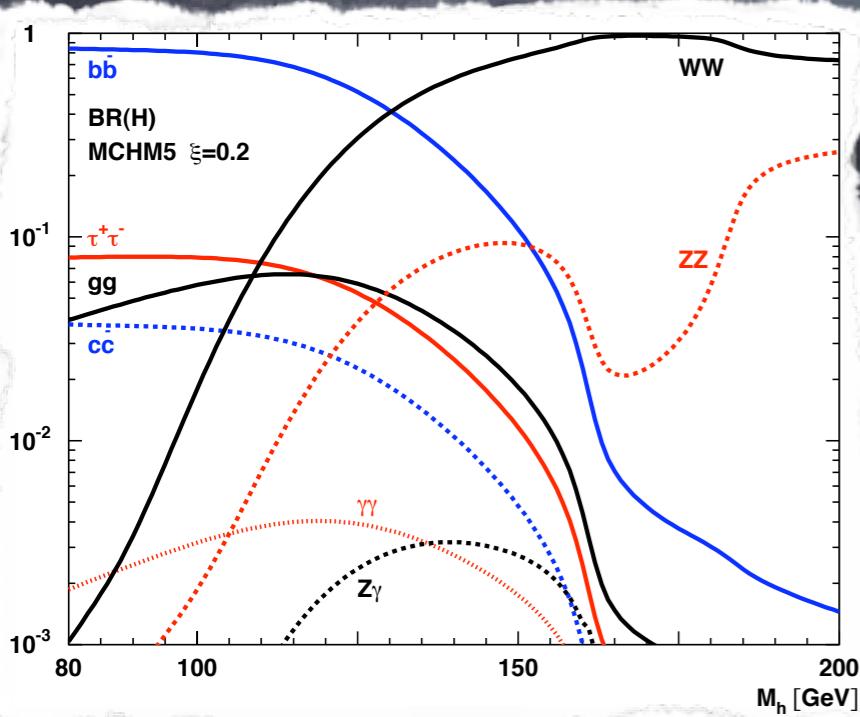
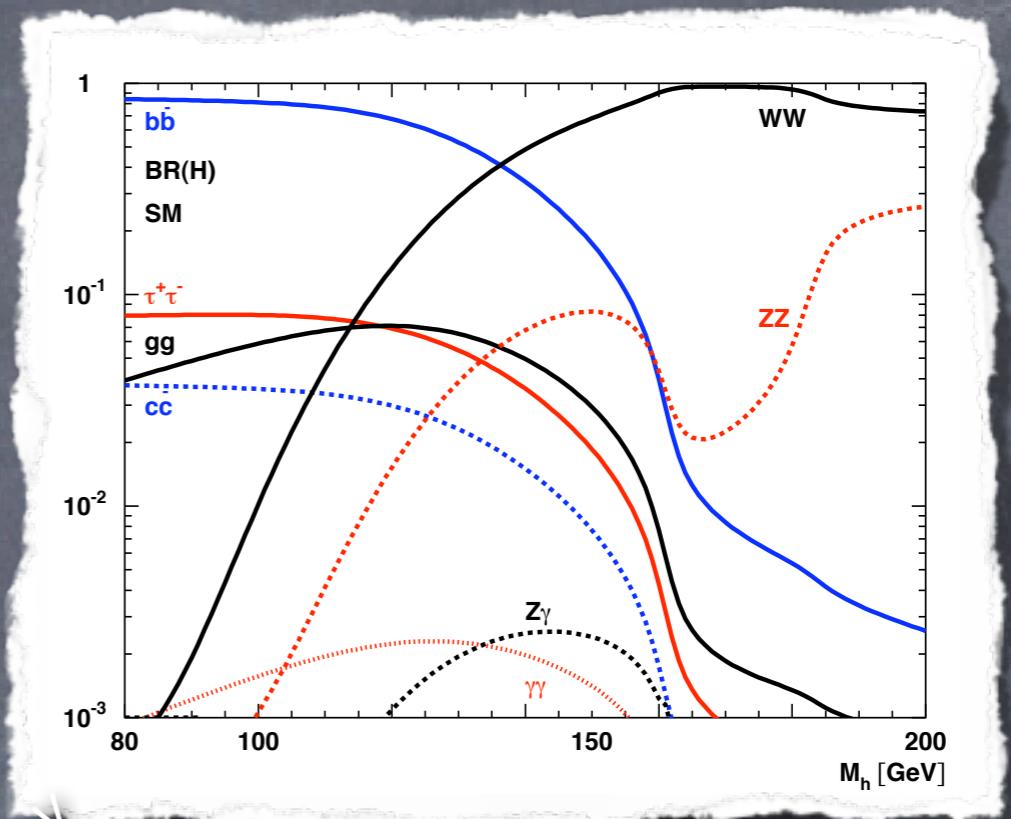
decay rates depends only on  $m_H$

**composite Higgs**

$4\pi f \sim 7 \text{ TeV}$

$4\pi f \sim 4.4 \text{ TeV}$

$4\pi f \sim 3 \text{ TeV}$

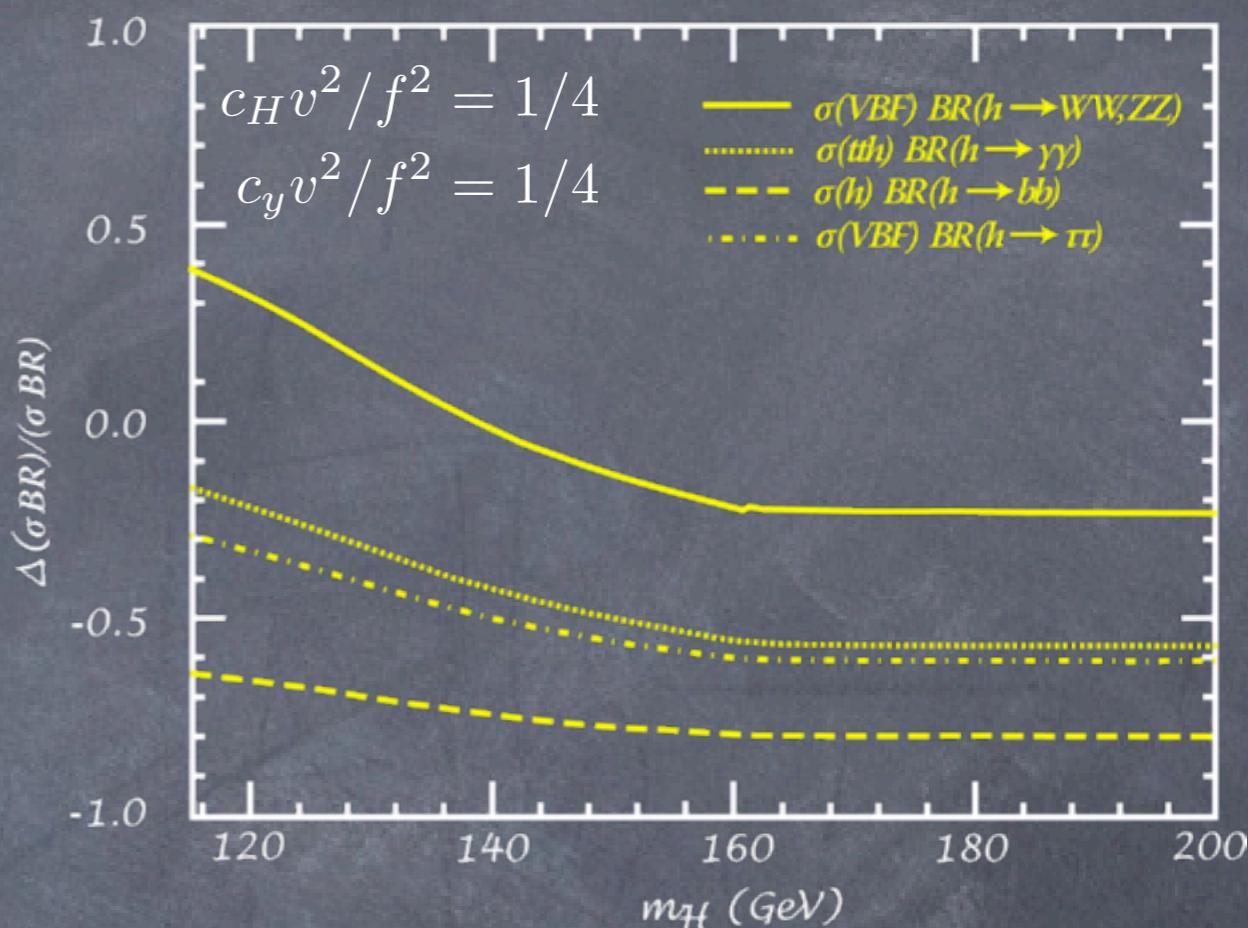
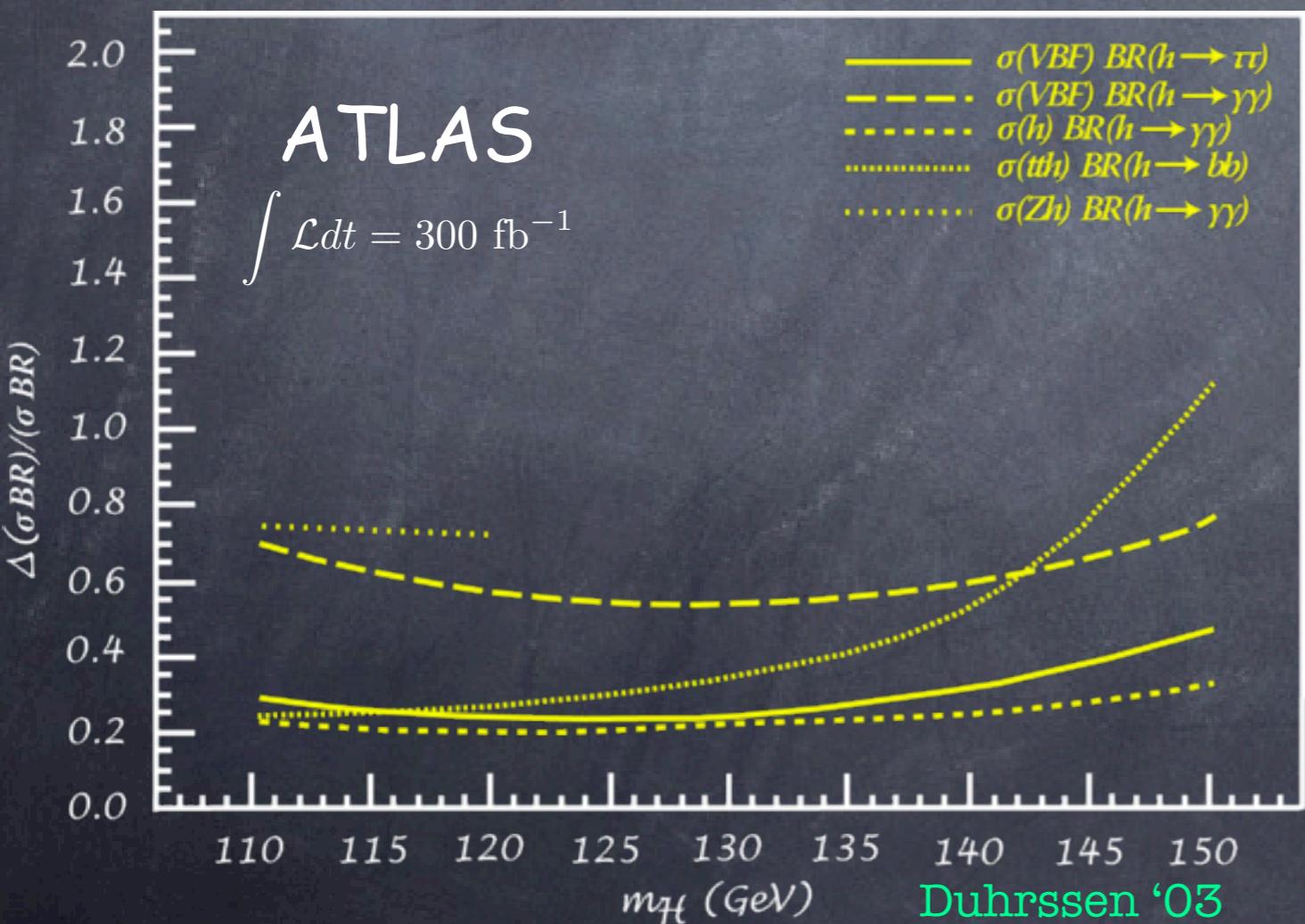


# Higgs anomalous couplings @ LHC

$$\Gamma(h \rightarrow f\bar{f})_{\text{SILH}} = \Gamma(h \rightarrow f\bar{f})_{\text{SM}} [1 - (2c_y + c_H) v^2/f^2]$$

$$\Gamma(h \rightarrow gg)_{\text{SILH}} = \Gamma(h \rightarrow gg)_{\text{SM}} [1 - (2c_y + c_H) v^2/f^2]$$

observable @ LHC?



LHC can measure

$$c_H \frac{v^2}{f^2}, \quad c_y \frac{v^2}{f^2}$$

up to 0.2-0.4

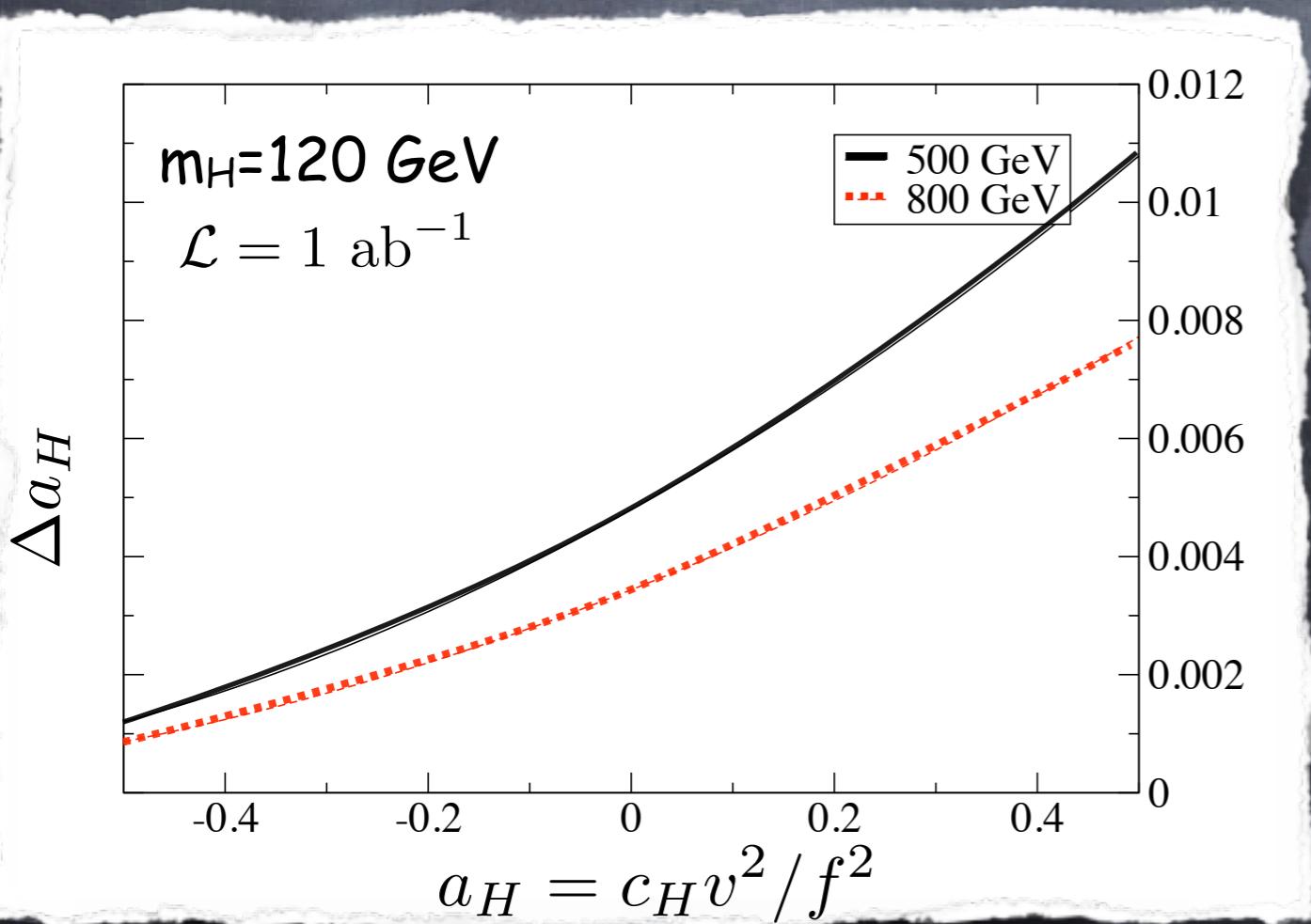
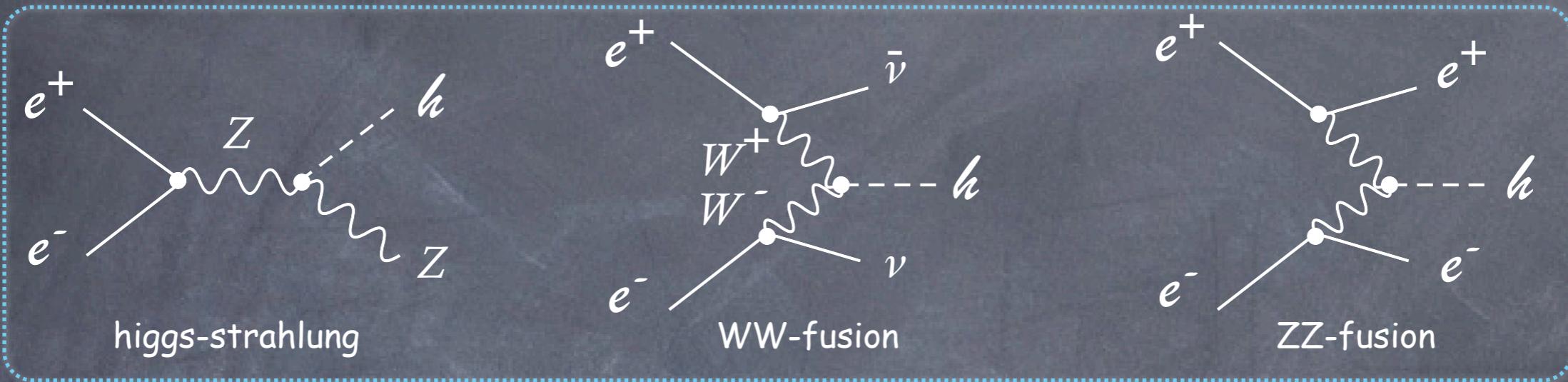
i.e.  $4\pi f \sim 5 - 7 \text{ TeV}$

(ILC could go to few % ie  
test composite Higgs up to  $4\pi f \sim 30 \text{ TeV}$ )

# Higgs anomalous couplings @ LC

Barger et al. hep-ph/0301097

single Higgs production



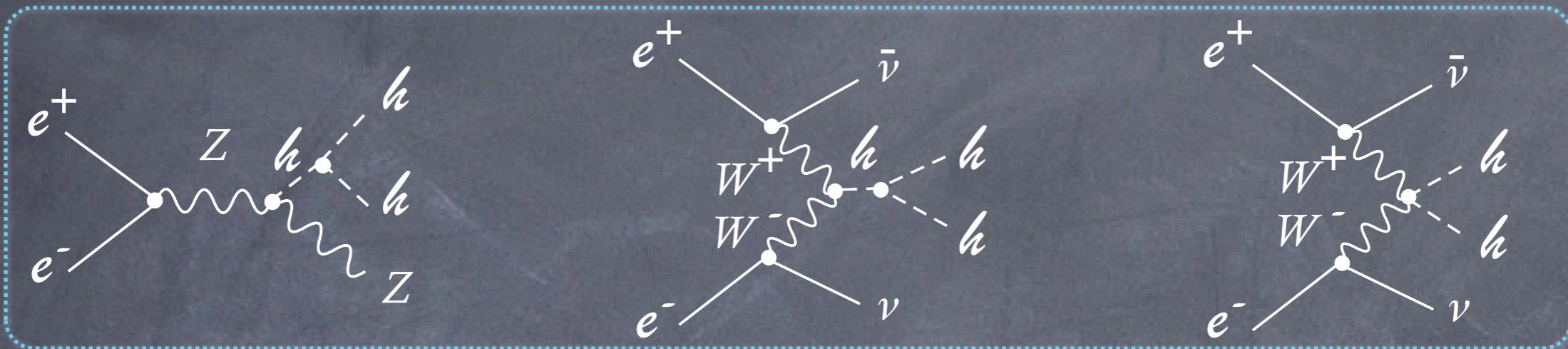
$$\Delta a_H \sim 0.005 \implies 4\pi f \sim 44 \text{ TeV}$$

$$\Delta a_H \sim 0.02 \implies 4\pi f \sim 22 \text{ TeV}$$

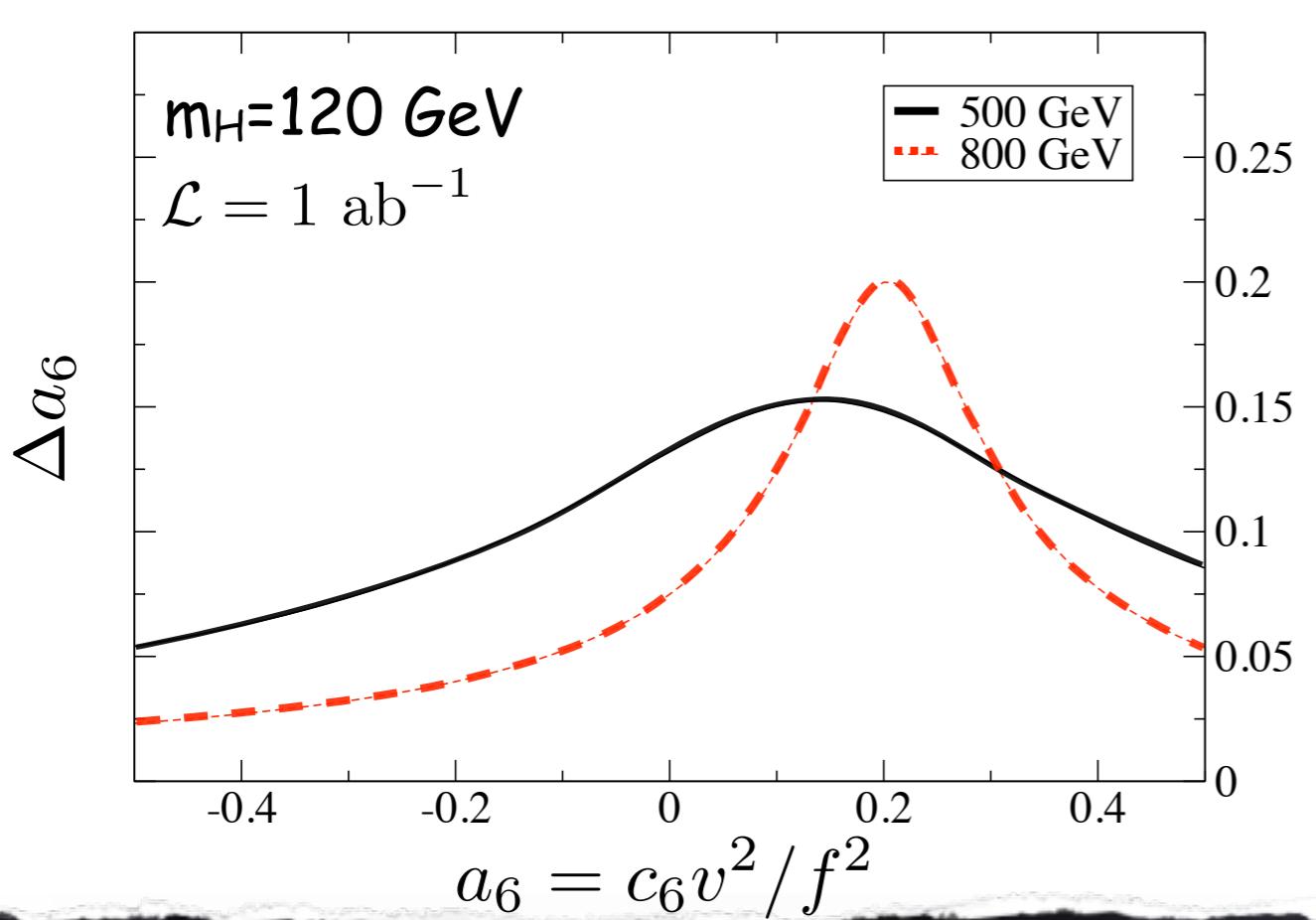
# Higgs anomalous (self-)couplings @ LC

Barger et al. hep-ph/0301097

## double Higgs production



the accuracy on  $a_H$  is not competitive compared to single Higgs production

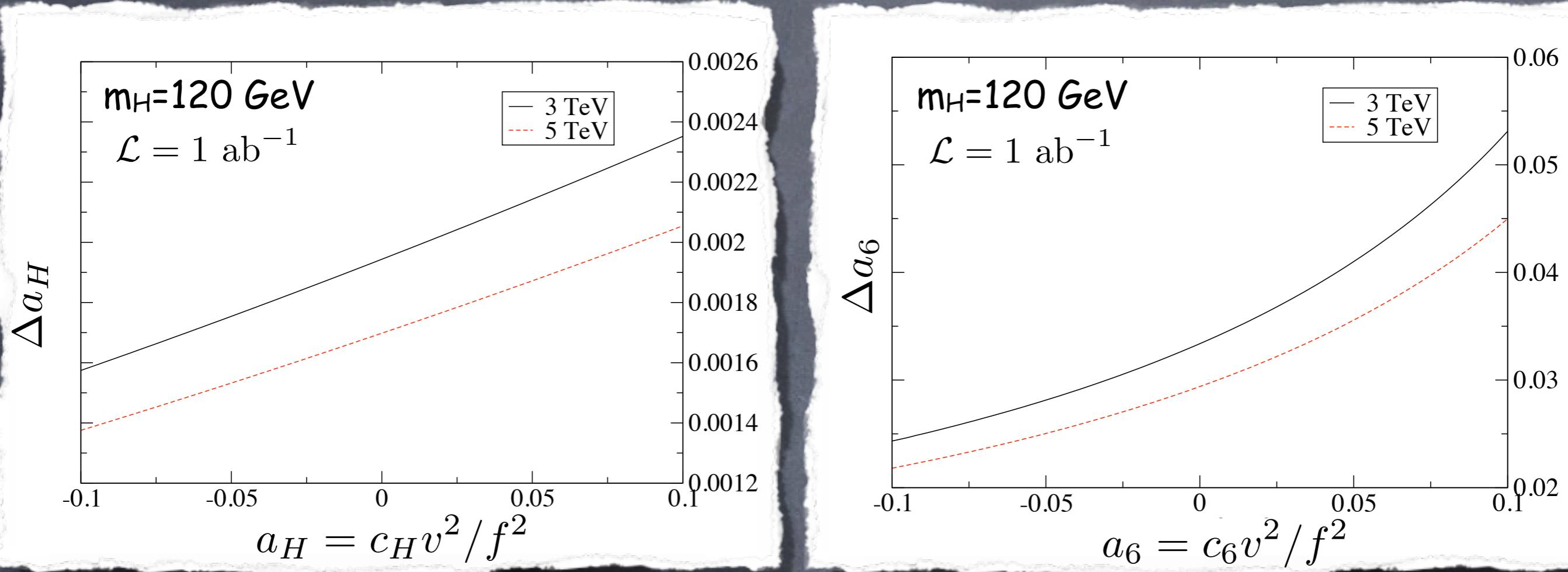


it allows to constrain  $a_6$

$$m_H = 120 \text{ GeV} \\ \Delta a_6 \sim 0.1 \implies 4\pi f \sim 10 \text{ TeV}$$

# Higgs anomalous couplings @ CLIC

Barger et al. hep-ph/0301097



$$\Delta a_H \sim 0.002 \Rightarrow 4\pi f \sim 70 \text{ TeV}$$

$$\Delta a_6 \sim 0.04 \Rightarrow 4\pi f \sim 15 \text{ TeV}$$

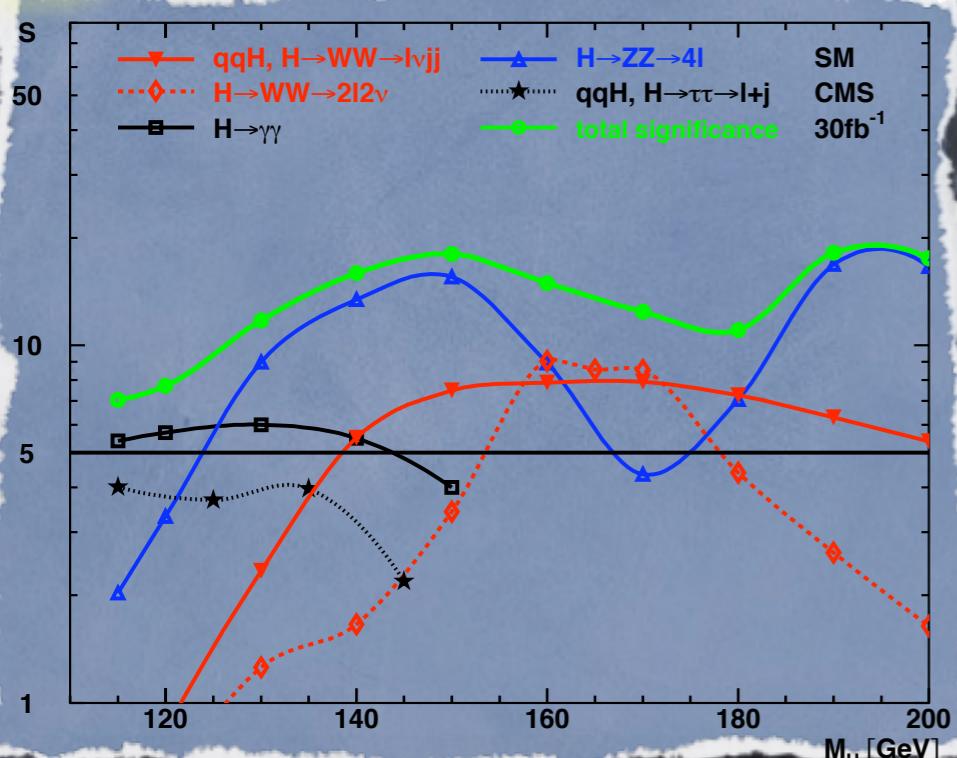
a factor 2 better than ILC

# Composite Higgs search @ LHC

Espinosa, Grojean, Muehlleitner '10

the modification of Higgs couplings and BRs affects the Higgs search

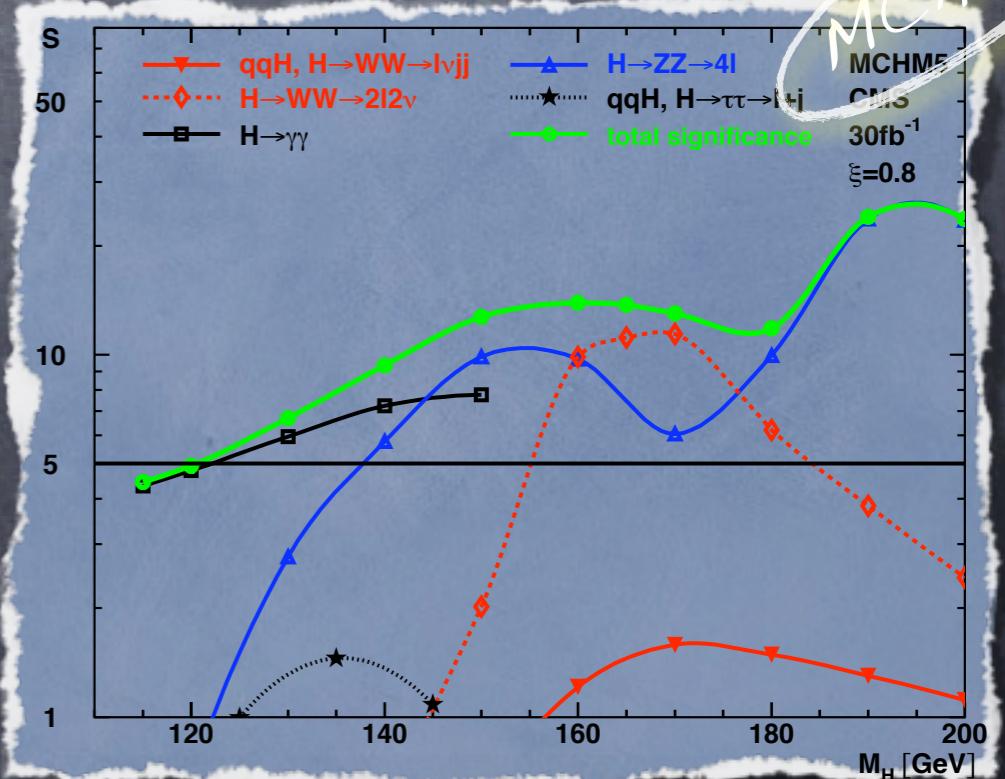
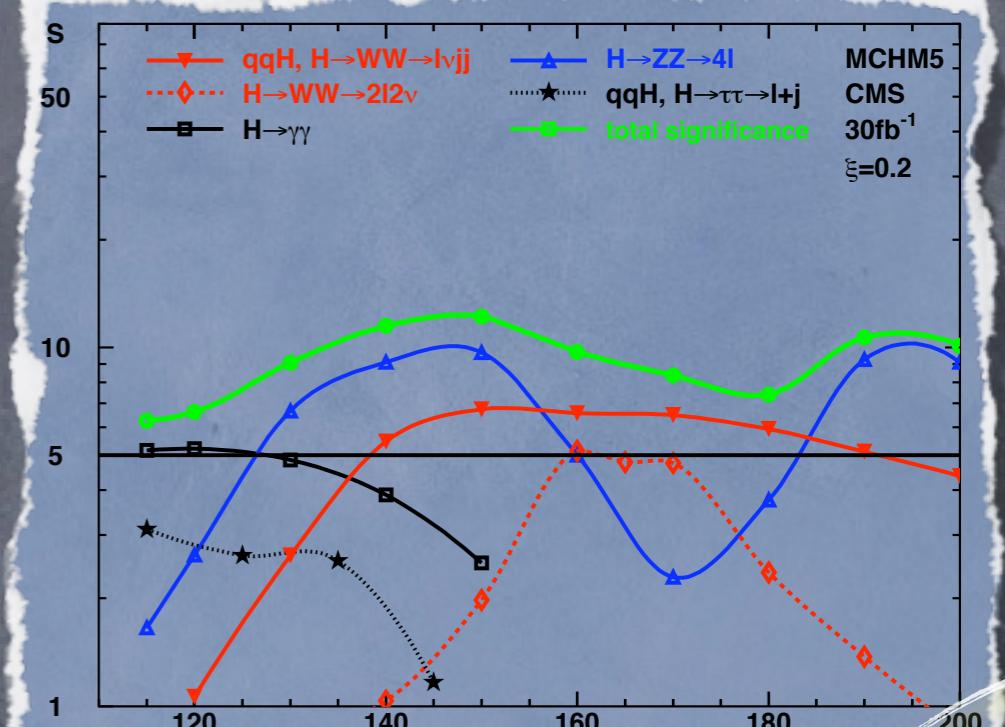
SM



large  
compositeness scale

signal significance  
for  $L=30/\text{fb}$

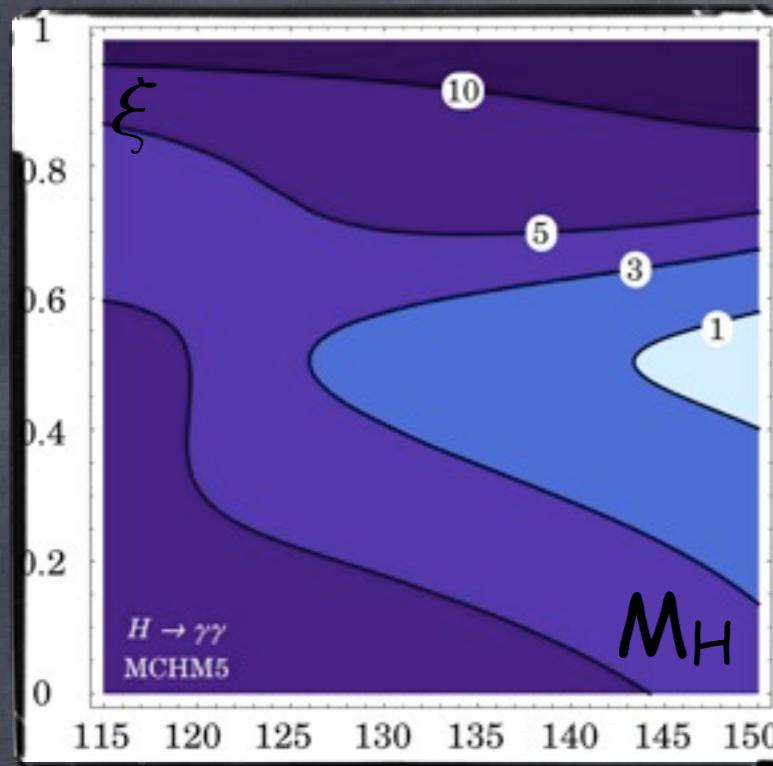
small  
compositeness scale



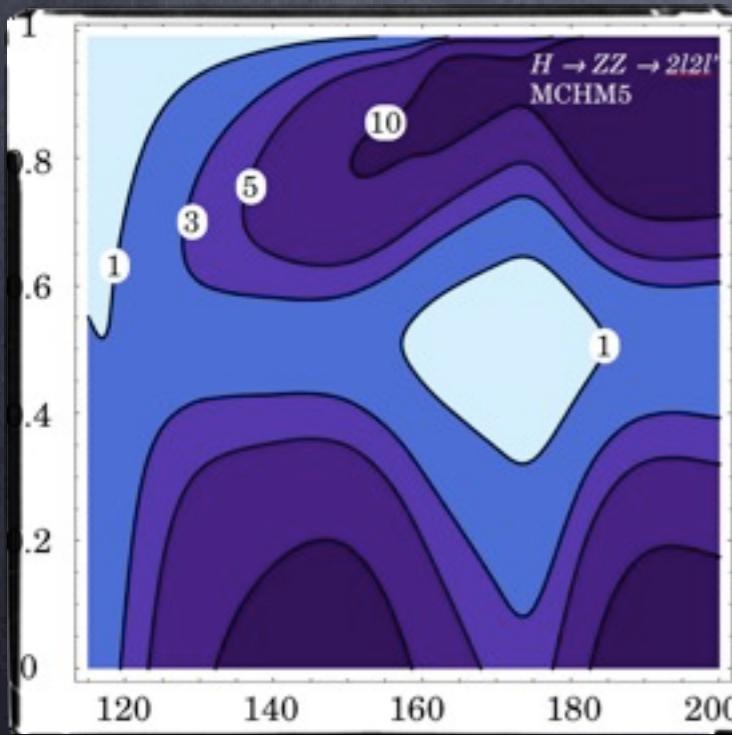
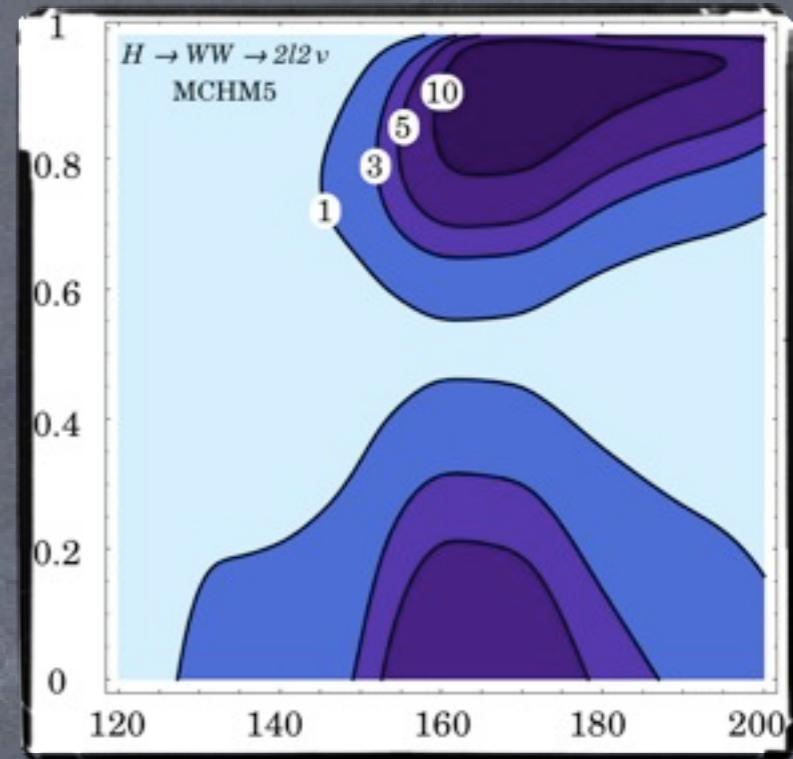
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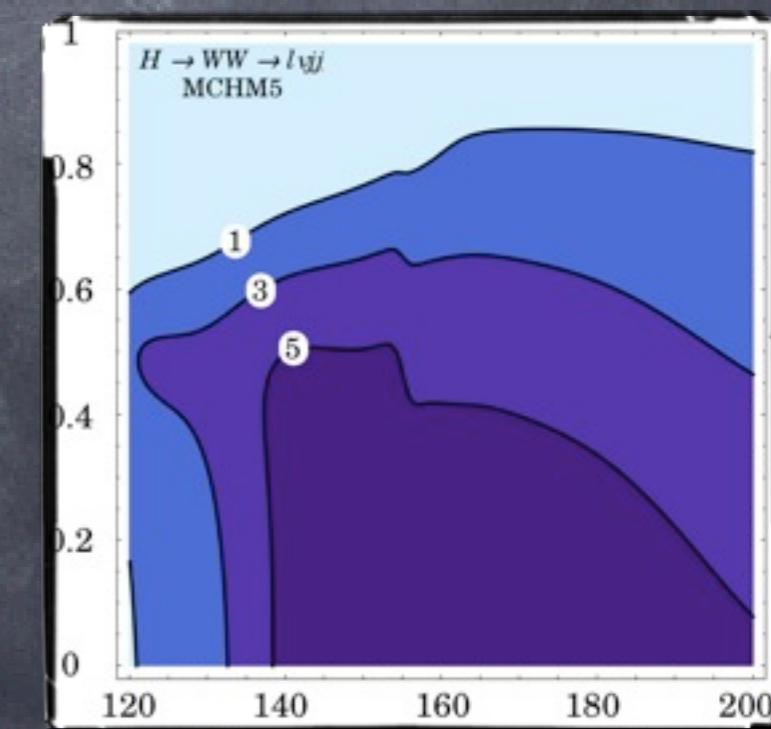
the modification of Higgs couplings and BRs affects the Higgs search



contour lines of  
signal significance  
for  $L=30/\text{fb}$   
in the  $(\xi, M_H)$  plane

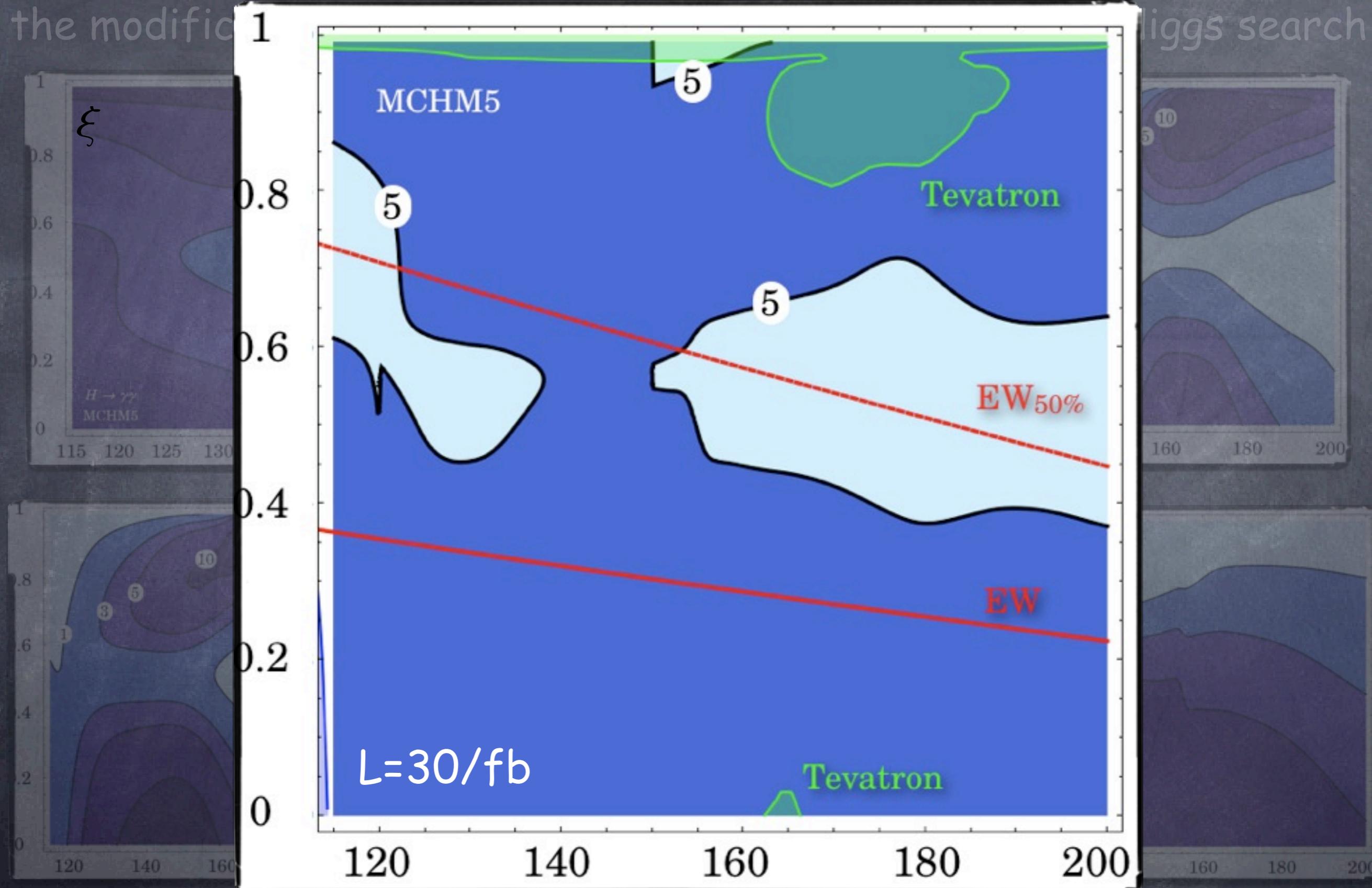


(neglect effects from heavy resonances)



# Composite Higgs search @ LHC

Espinosa, Grojean, Muehleitner '10



# No Higgs timeline

What is the scale of strong WW scattering?

Contino, Grojean, Moretti, Piccinini, Rattazzi '10

$$\mathcal{A}_{TT \rightarrow TT} \sim g^2 f(t/s)$$

f is a rational fct  
expected O(1) for  $t \sim -s/2$

onset of strong scattering at the weak scale

$$\mathcal{A}_{LL \rightarrow LL} \sim \frac{s}{v^2}$$

hard cross-section

$$\left. \frac{d\sigma_{LL \rightarrow LL}/dt}{d\sigma_{TT \rightarrow TT}/dt} \right|_{t \sim -s/2} = N_h \frac{s^2}{M_W^4}$$

'inclusive' cross-section

$$(-s + Q_{\min}^2 < t < -Q_{\min}^2)$$

$$\frac{\sigma_{LL \rightarrow LL}(Q_{\min})}{\sigma_{TT \rightarrow TT}(Q_{\min})} = N_s \frac{s Q_{\min}^2}{M_W^4}$$

$$N_h \sim 1$$

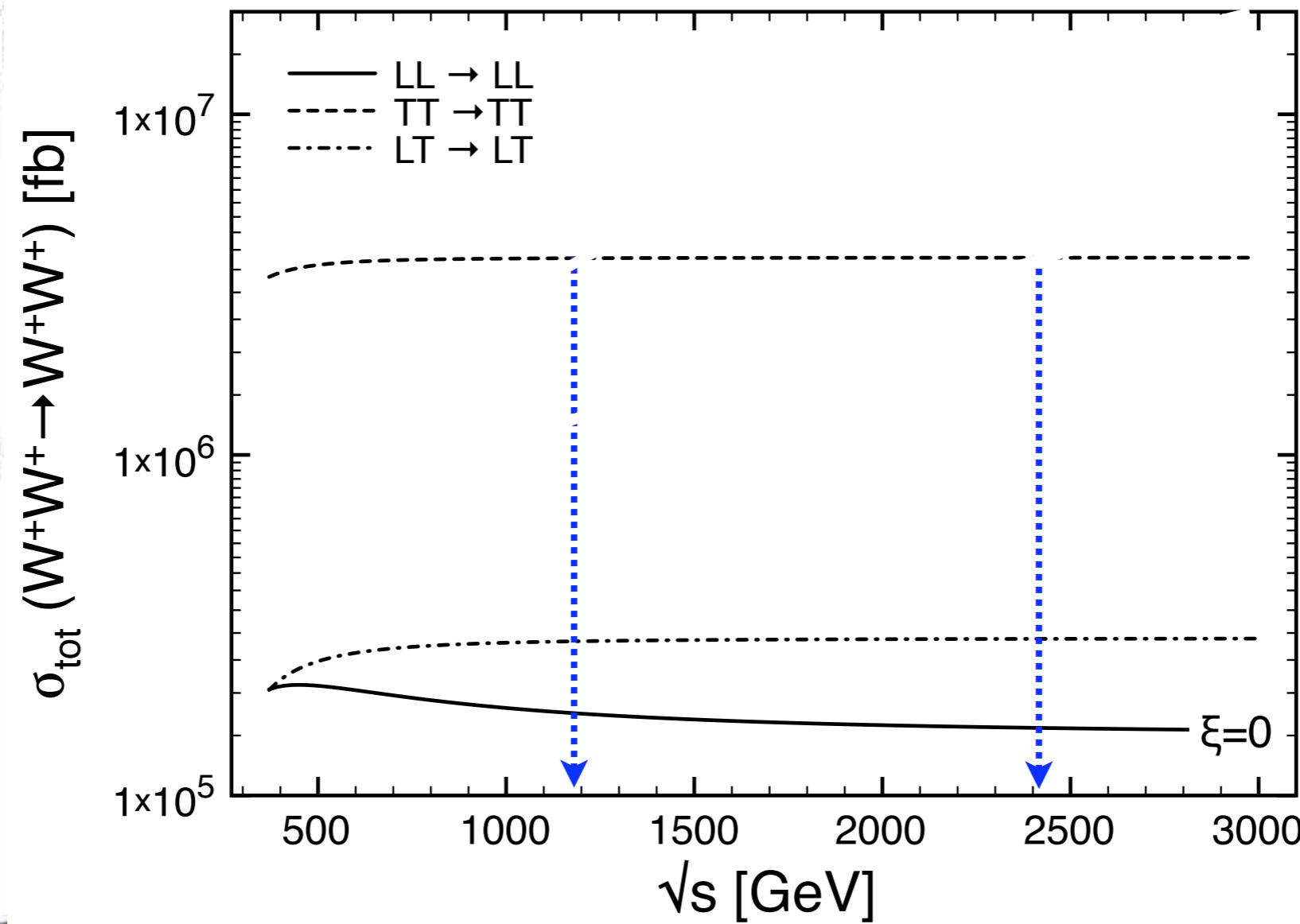
NDA estimates

$$N_s \sim 1$$

We should expect strong scattering to show up around the weak scale

# Total cross sections

## disentangling L from T polarization is hard



The onset of strong scattering is delayed to larger energies due to  
the dominance of  $TT \rightarrow TT$  background

The dominance of T background will be further enhanced by the pdfs  
since the luminosity of  $W_T$  inside the proton is  $\log(E/M_W)$  enhanced

# Coulomb enhancement (SM)

the total cross section is dominated by the poles  
in the exchange of  $\gamma$  and  $Z$  in the t- and u-channels

$$W^+ W^+ \rightarrow W^+ W^+$$

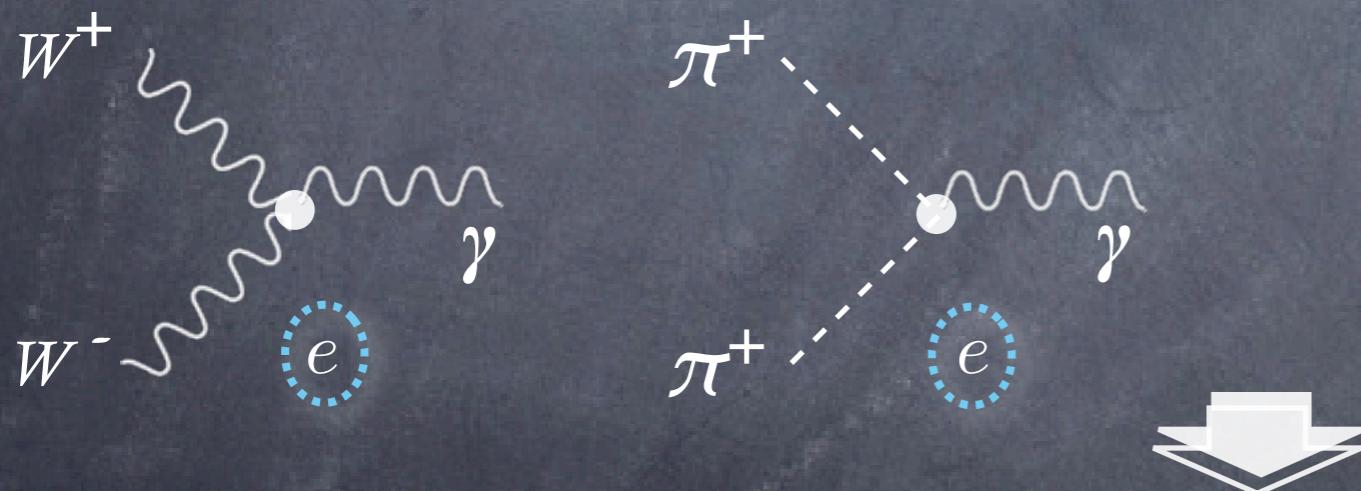
$$\mathcal{A} = \frac{a_\gamma^t s}{t} + \frac{a_Z^t s}{t - M_Z^2} + \frac{a_\gamma^u s}{u} + \frac{a_Z^u s}{u - M_Z^2} + \dots \Rightarrow \sigma \sim \frac{1}{16\pi} \left( \frac{{a_\gamma^t}^2 + {a_\gamma^u}^2}{M_\gamma^2} + \frac{{a_Z^t}^2 + {a_Z^u}^2}{M_\gamma^2 + M_Z^2} \right)$$

$M_\gamma$  = régulateur of Coulomb singularity=off-shellness of  $W \sim M_W$

## eikonal limit

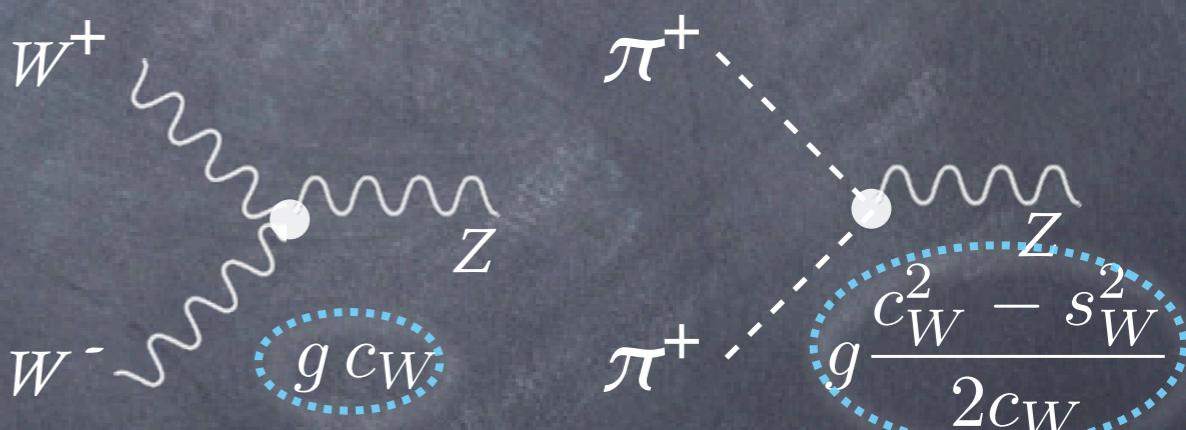
$$a_\gamma = 2 \cdot (\text{electric charge of } W^+)^2$$

universal for T and L



$$a_Z = 2 \cdot (\text{"SU(2) charge" of } W^+)^2$$

different for T and L



SM

$$\frac{\sigma_{TT \rightarrow TT}}{\sigma_{LL \rightarrow LL}} \sim 20$$

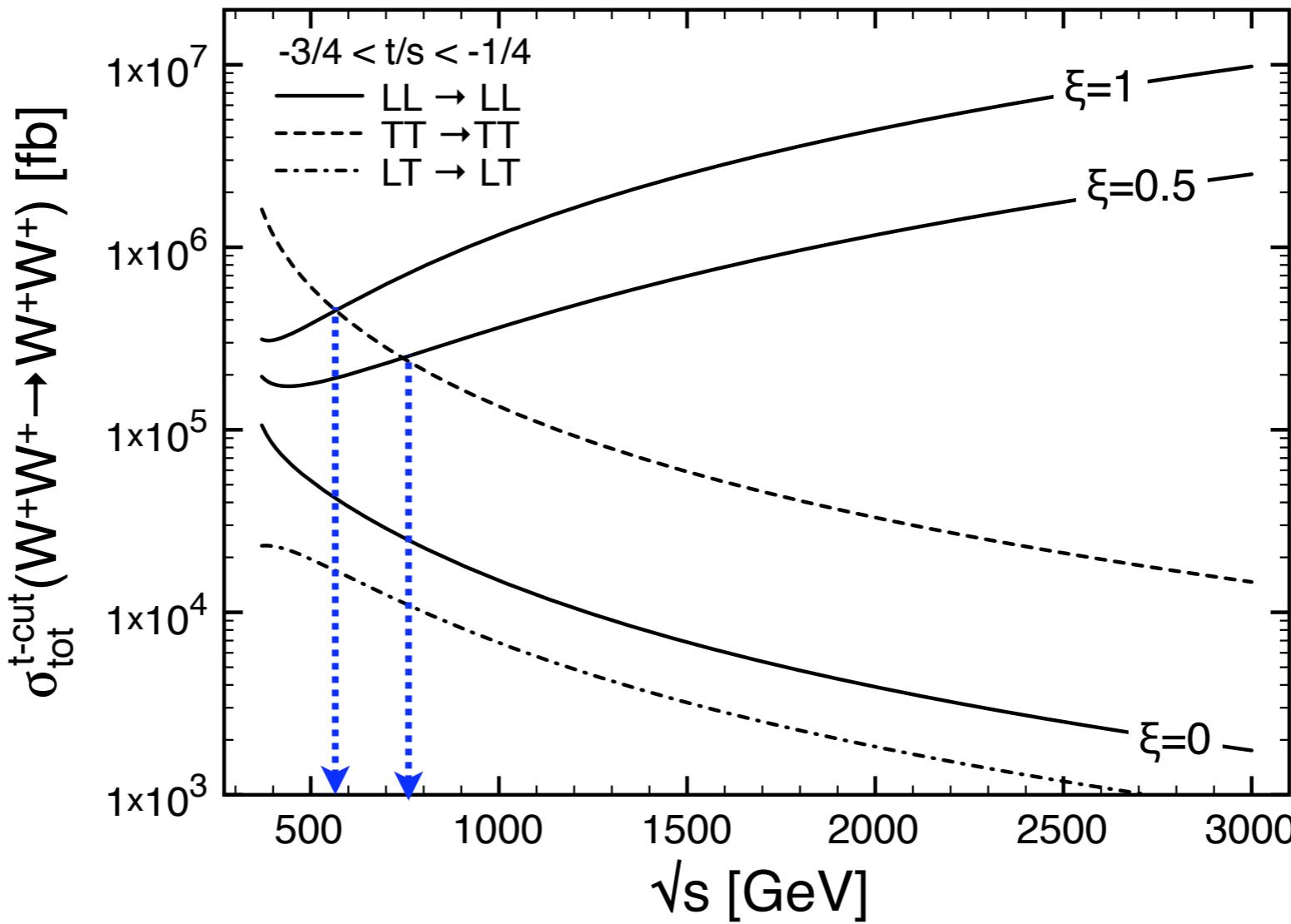
(for  $M_\gamma \sim M_Z$ )

$$N_s \sim 1/500$$

⇒ T-dominance is the result of multiplicity and larger SU(2) charges ⇐

# Hard scattering (central region)

we need to look at the central region, i.e. large scattering angle,  
to be sensitive to strong EWSB



$$\frac{\sigma_{LL \rightarrow LL}^{\text{hard}}}{\sigma_{TT \rightarrow TT}^{\text{hard}}} \simeq \left( \frac{\sqrt{s}}{7.4 M_W} \right)^4 \xi^2$$

- hard cross-section = faster growth with energy
- onset of strong scattering still at high scale

$$N_h = 1/2304$$

# Triple gauge boson couplings (TGC) @ LC

$$\mathcal{L}_V = -ig \cos \theta_W g_1^Z Z^\mu (W^{+\nu} W_{\mu\nu}^- - W^{-\nu} W_{\mu\nu}^+) - ig (\cos \theta_W \kappa_Z Z^{\mu\nu} + \sin \theta_W \kappa_\gamma A^{\mu\nu}) W_\mu^+ W_\nu^-$$

TGC are generated by heavy resonances

$$g_1^Z = \frac{m_Z^2}{m_\rho^2} c_W \quad \kappa_\gamma = \frac{m_W^2}{m_\rho^2} \left( \frac{g_\rho}{4\pi} \right)^2 (c_{HW} + c_{HB}) \quad \kappa_Z = g_1^Z - \tan^2 \theta_W \kappa_\gamma$$

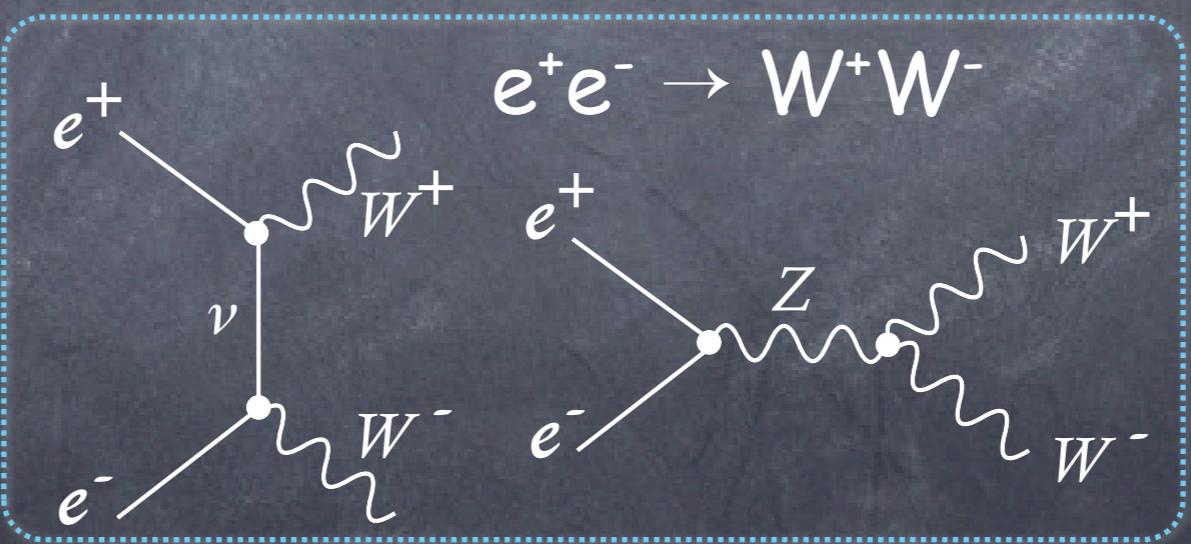
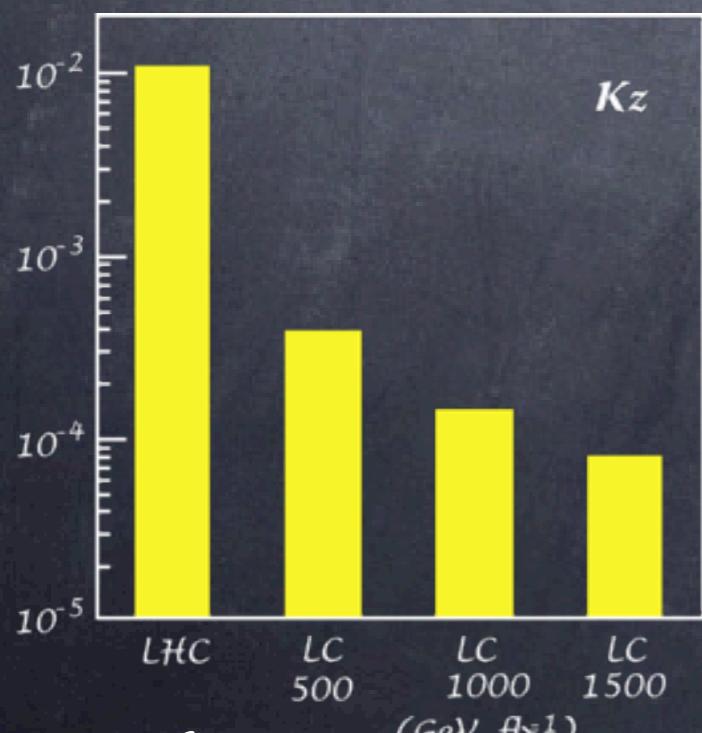
@ LHC  $100\text{fb}^{-1}$

$$g_1^Z \sim 1\% \quad \kappa_\gamma \sim \kappa_Z \sim 5\%$$

sensitive to resonance  
up to  $m_\rho \sim 800 \text{ GeV}$

not competitive with the measure of S at LEPII

@ ILC



0.1% accuracy  $\Rightarrow$

sensitive to resonance  
up to  $m_\rho \sim 8 \text{ TeV}$

T. Abe et al, Snowmass '01

# Conclusions

LHC is prepared to discover the "Higgs"

collaboration EXP-TH is important to make sure  
e.g. that no unexpected physics (unparticle, hidden valleys) is missed (triggers, cuts...)

Should not forget that the LHC will be a (quark) top machine

and there are many reasons to believe that the top is an important agent of the Fermi scale

If we are lucky we might discover new physics rather early  
but if we want to understand the physics responsible for EWSB  
we'll certainly need more luminosity

even if LHC sees the Higgs and nothing else, there is a strong  
physics case for the ILC to understand the dynamics of EWSB

