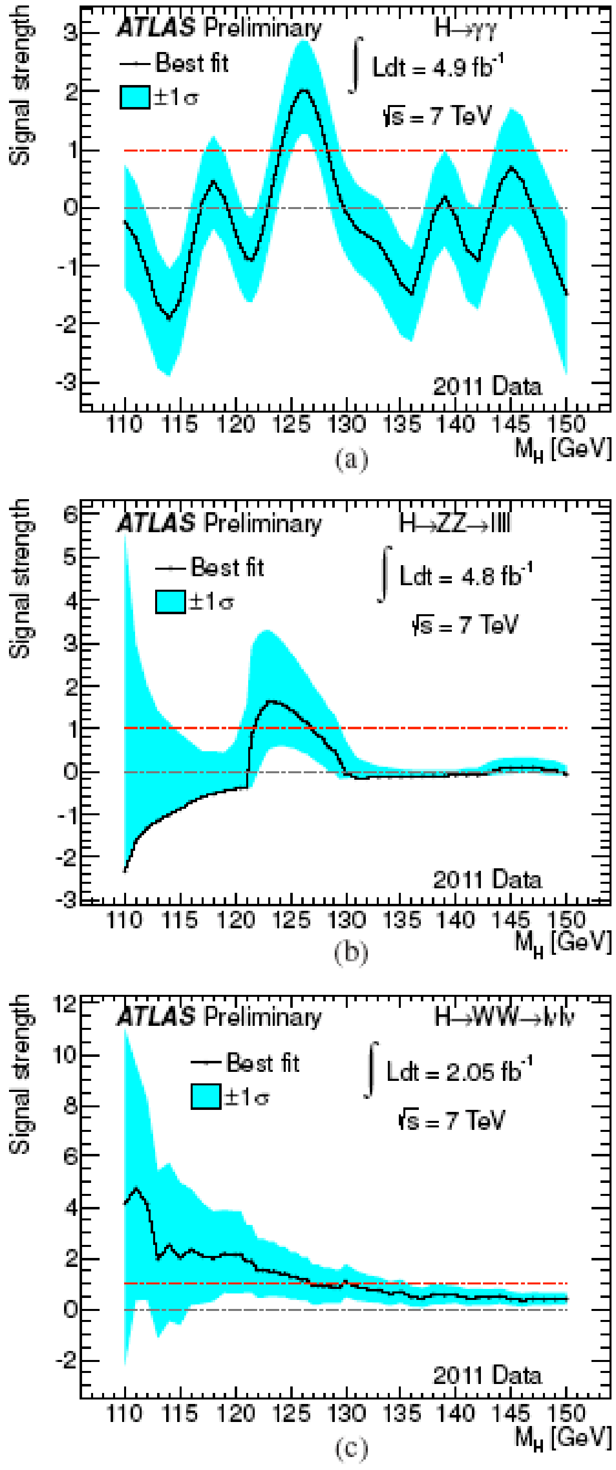


Thoughts about the Case for the ILC

M. E. Peskin
SiD Workshop
December 2011

This talk was originally called "Report from the ILC Physics Common Task Group".

I will report on what we are doing in the Physics CTG, but it would also like to make some personal remarks probably not endorsed by this group.

I will try to keep the distinction clear.

I will begin with Physics CTG report.

If the ILC is putting forward a technical proposal, this must be accompanied by a restatement of the ILC physics case.

In the Physics and Detector organization, we discussed how this statement might be organized. The discussion of the physics case is related to the detector baselining process, but it is logically separate.

The Physics CTG has taken responsibility for producing this document. It will be a "Physics Chapter", a separate volume of the DBD.

The organization of the Physics Chapter will be the following (with the section convenors named):

0: Introduction: The advantages of e+e-
Jaehoon Yu, Michael Peskin
1: W and Z (including WW scattering)
Tim Barklow, Juergen Reuter
2: Two-fermion production (including Z' and extra dimensions)
Yuanning Gao, Maxim Perelstein
3: Top Quark
Andrei Nomerotski, Andre Hoang
4: Standard Model Higgs
Keisuke Fujii, Heather Logan
5: Extended Higgs Sectors
Aurore Savoy-Navarro, Shinya Kanemura
6: Supersymmetry and other new spectroscopy
Jenny List, Howard Baer
7: Connection to Cosmology
Geraldine Servant, Tim Tait

This structure and the contact information for the convenors is given at:

http://www.slac.stanford.edu/~mpeskin/PhysicsChapter.html

Our plan is not to rewrite the major physics report produced for the 2007 RDR. Our goals are

1. To state the major elements of the physics case clearly.
2. To update the discussion to include the results of the LOI and benchmarking studies
3. To include new physics information, especially from the LHC

We will organize sessions at the LC meetings in 2012, including Daegu and U T Arlington. Note also the LC Forum at DESY

LC Forum, DESY, Feb. 7-9, 2012
https://indico.desy.de/conferenceDisplay.py?confId=4980

Our deadline for a public draft is Sept. 1, 2012, to be in time for input to the European Strategy Study.   We will do a revision for the DBD submission.

It is unclear which points will get major emphasis in our report. This depends of the results shown by ATLAS and CMS at the ICHEP conference (~10 fb-1).

Our contract is to make the best possible case for the ILC at 500 GeV, defined by the Technical Design Report.   This is needed input to the question of what is the best strategy for the future of HEP.

If you would like to get involved in the preparation of this report, please contact me or one of the relevant convenors.

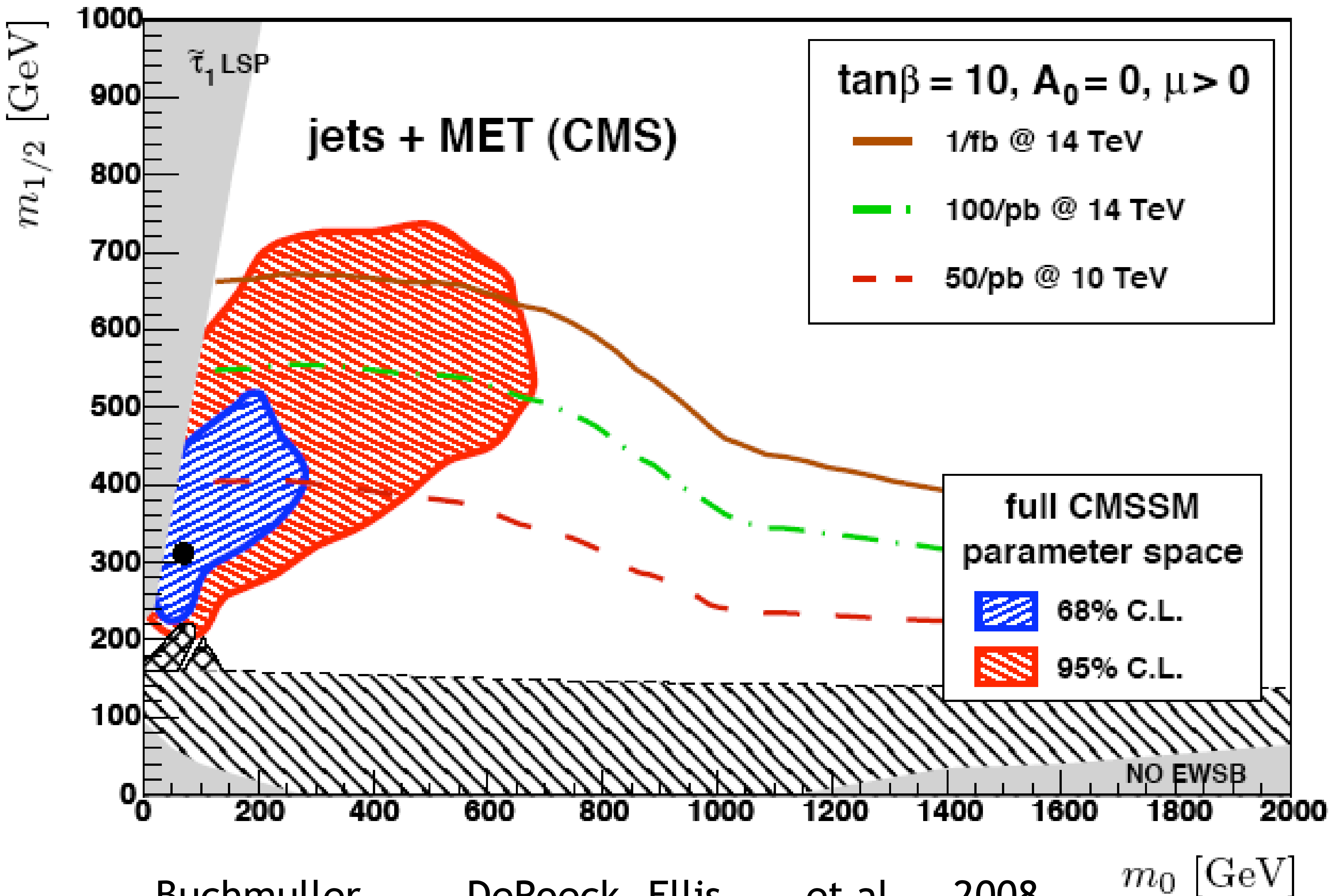
Now I will take off my convenor’s hat and give you a personal discussion of ILC and LC physics.

Most people in the LC community were hoping, not only for physics beyond the Standard Model, but for a relatively light new particle spectrum that would be found early in the LHC program.

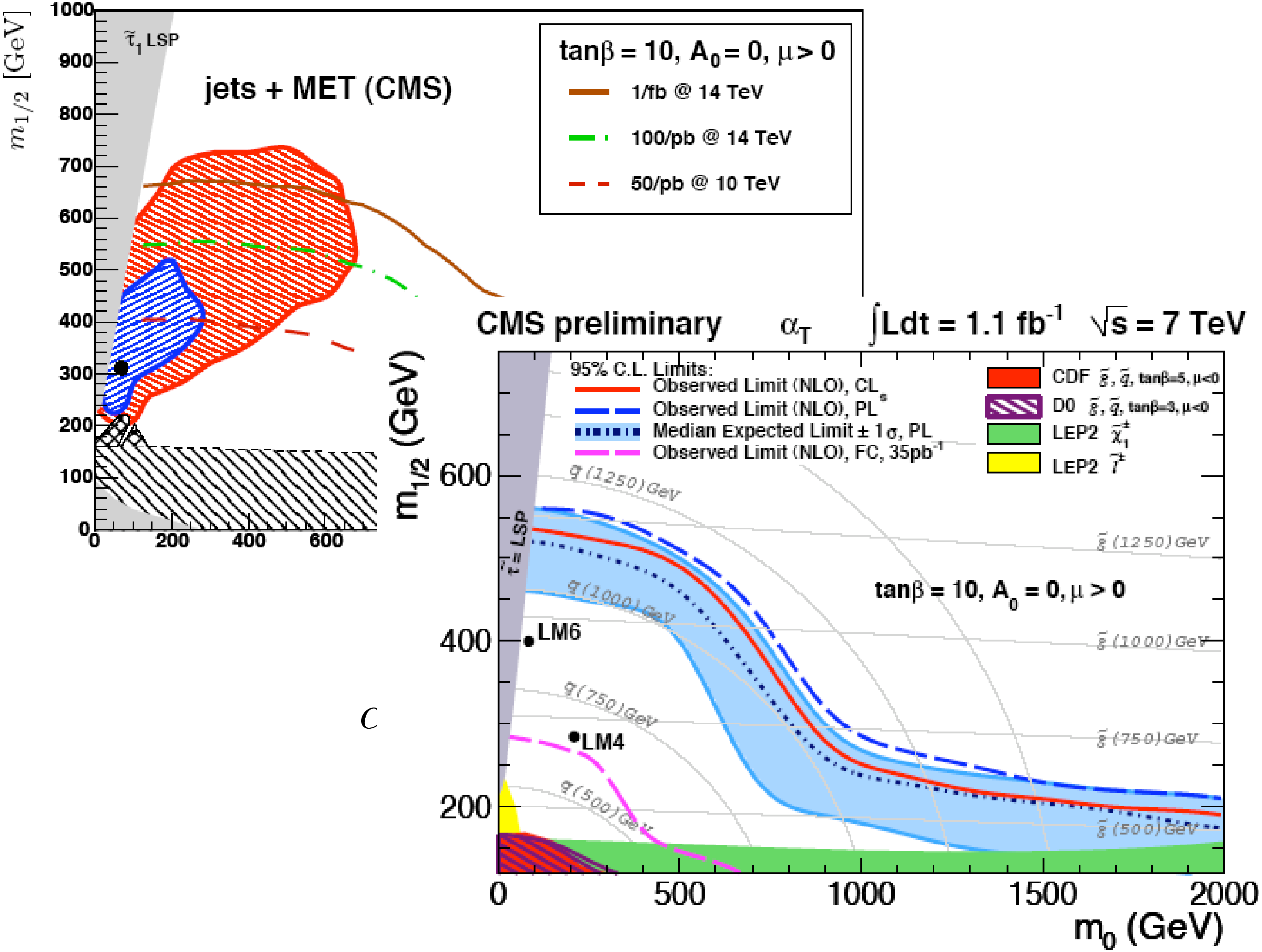
Nature did not agree.

We have seen no evidence for new physics in the first 1-2 fb-1. Many interesting models have been excluded.

However, yesterday, we heard interesting evidence for a particle with the properties of the Standard Model Higgs boson, with a mass near 125 GeV.



Buchmuller, ... , DeRoeck, Ellis ..., et al. 2008



jets + MET (CMS)
tanβ = 10, A0 = 0, μ > 0
1/fb @ 14 TeV
100/pb @ 14 TeV
50/pb @ 10 TeV
τ̃1 LSP
m1/2 [GeV]
CMS preliminary αT ∫Ldt = 1.1 fb-1 √s = 7 TeV
95% C.L. Limits:
Observed Limit (NLO), CLs
Observed Limit (NLO), PL
Median Expected Limit ± 1σ, PL
Observed Limit (NLO), FC, 35pb-1
CDF g̃, q̃, tanβ=5, μ<0
D0 g̃, q̃, tanβ=3, μ<0
LEP2 χ̃±1
LEP2 l̃±
tanβ = 10, A0 = 0, μ > 0
LM6
LM4
τ̃ = LSP
m1/2 (GeV)
m0 (GeV)
C

If nothing is seen in 2 fb-1, is there a realistic chance of observing new physics in 10 fb-1 ?

I believe that the answer to this question is yes.

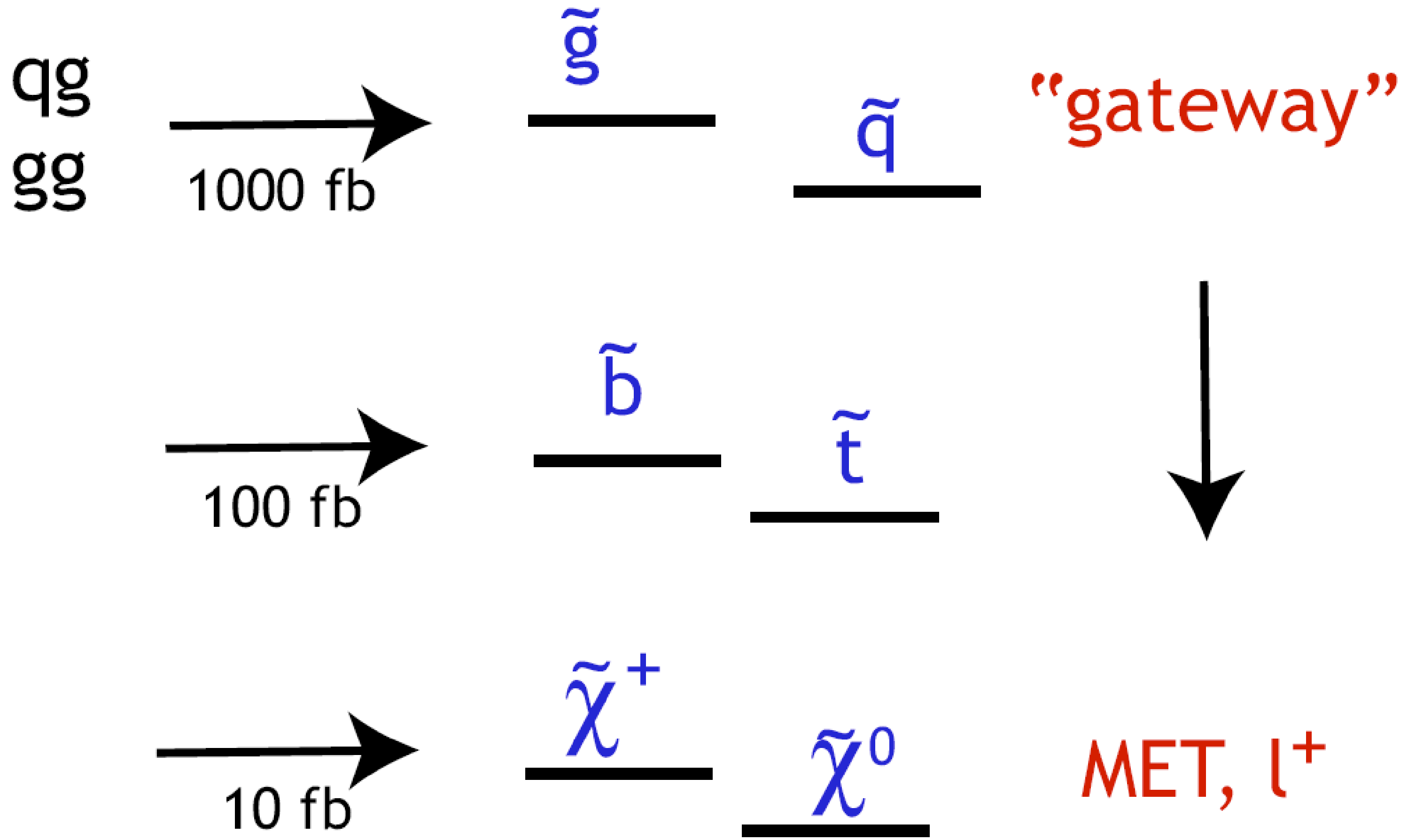
The three top candidates, in my opinion, are

light top squark,   with mass about 400 GeV

vectorlike heavy top quark, with mass about 600 GeV

long-lived stable particles produced with fb cross section

Here is a useful caricature of SUSY phenomenology at hadron colliders:



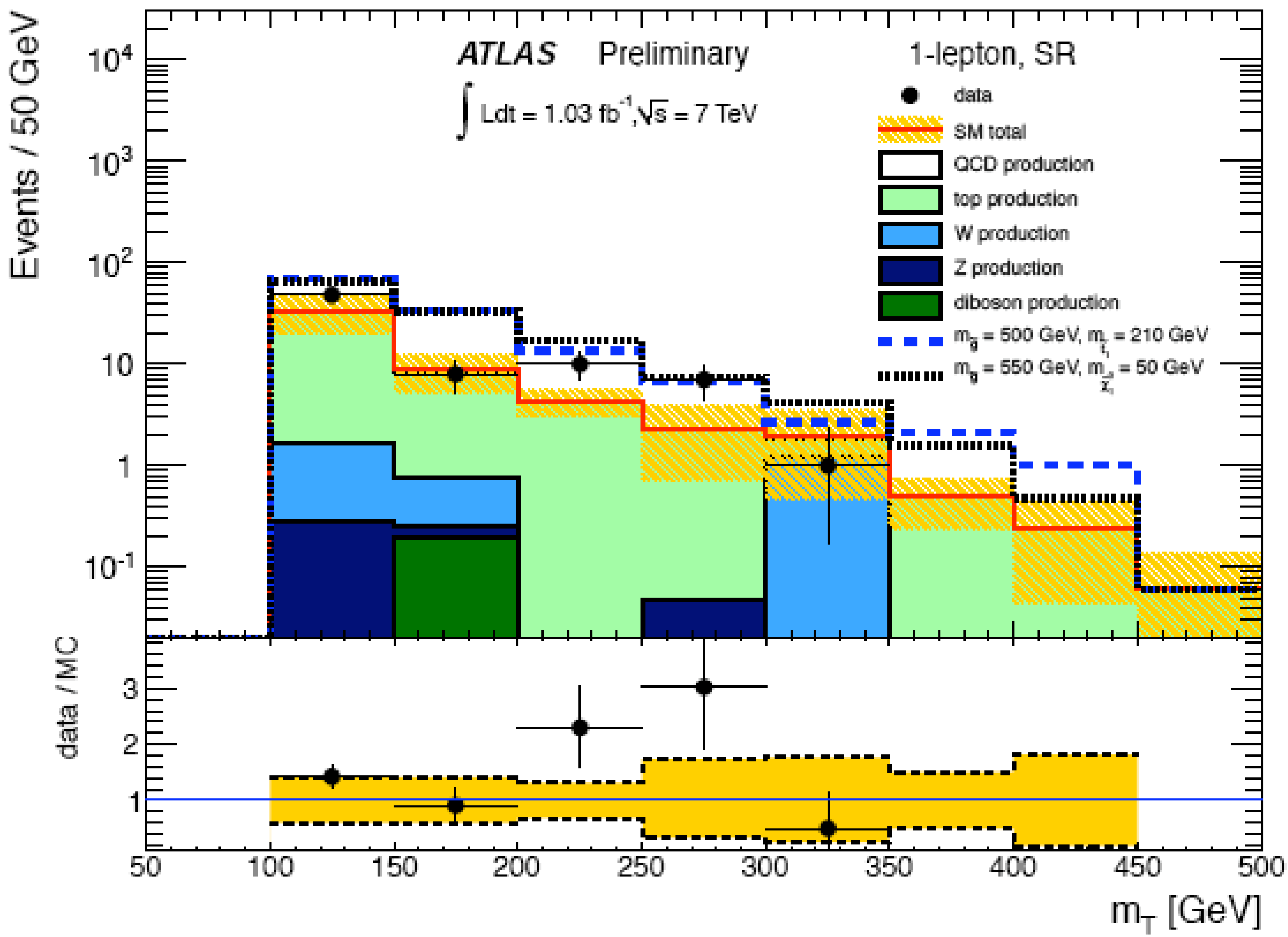
The exotic and characteristic signatures of SUSY are at the bottom. The gateway channel is at the top. If a channel is not allowed energetically, we must defer to the next one.

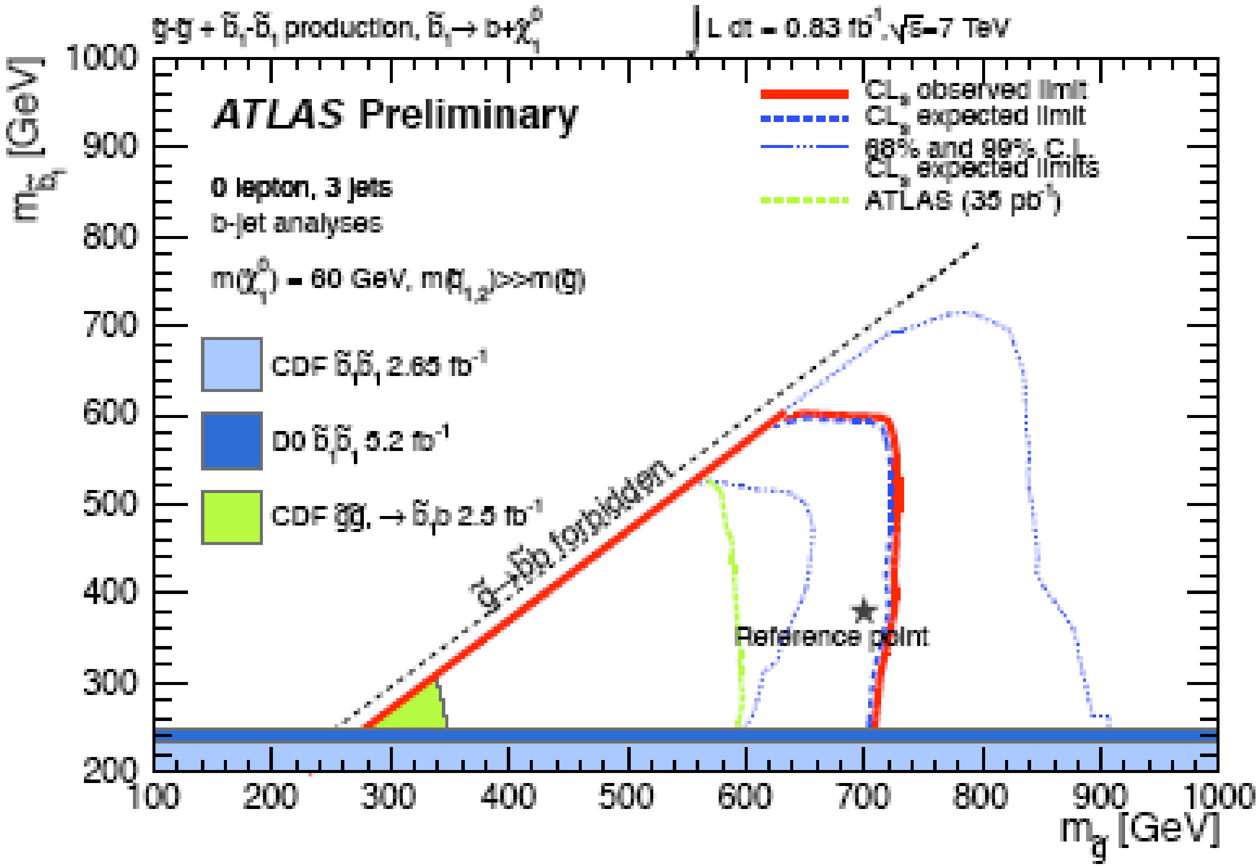
The squark, gluino gateway is almost exhausted, but the processes of direct stop, sbottom production are not yet explored.

Gauge-mediated SUSY breaking has a preference for a stau that is stable on collider-physics time scales.   This particle can trigger the muon system, so LHC searches are very sensitive. This is the easiest route to higher-mass SUSY.

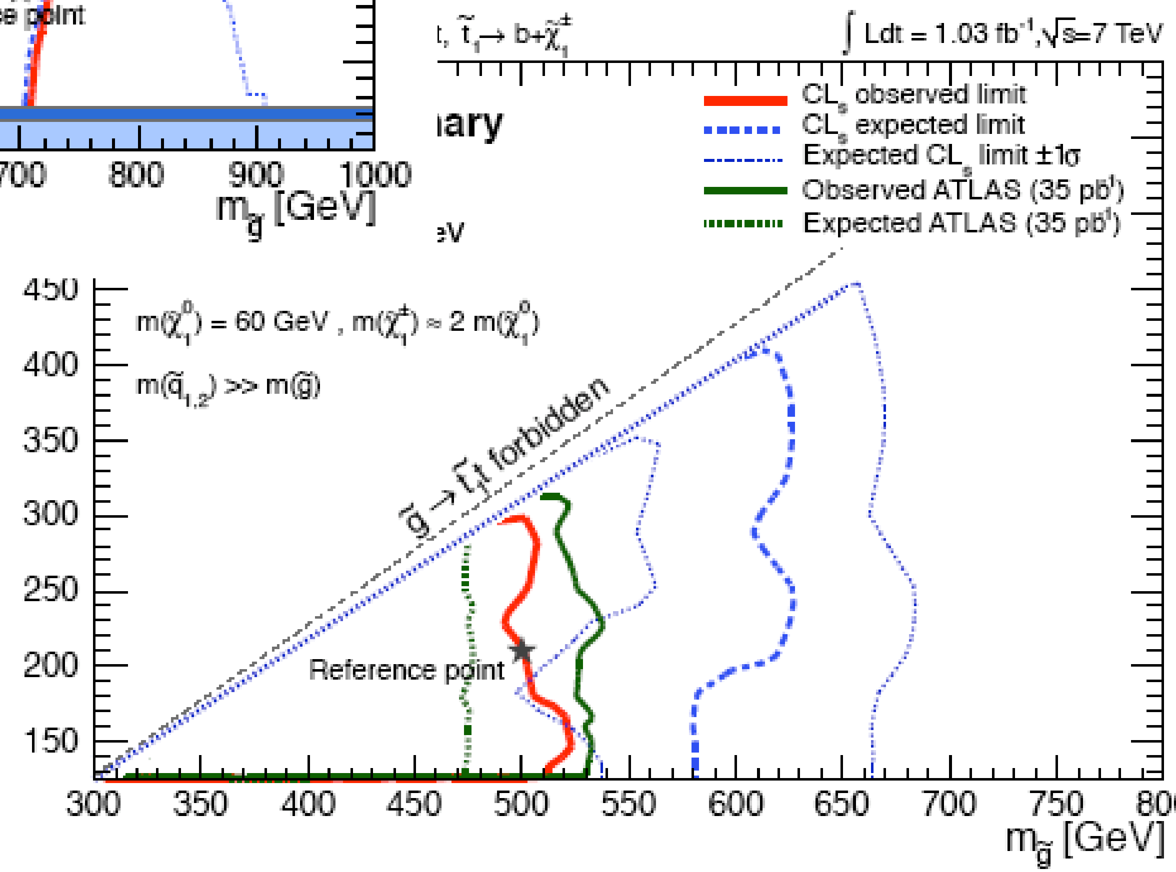
Vectorlike quarks are expected in Little Higgs, extra dimension, and other composite Higgs theories. The signature is obvious, but so far statistics are lacking.

ATLAS search for b-jets + lepton + MET

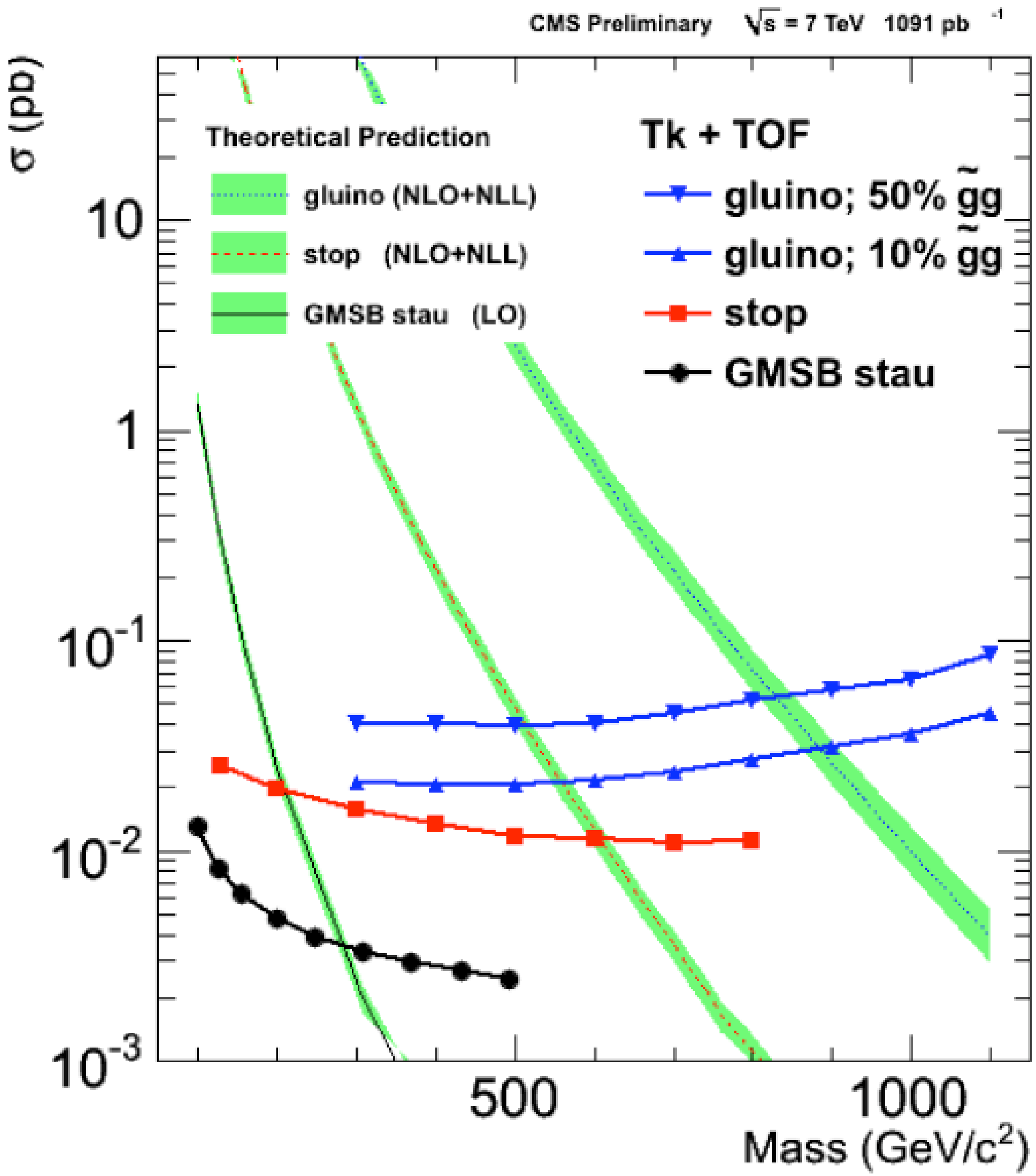


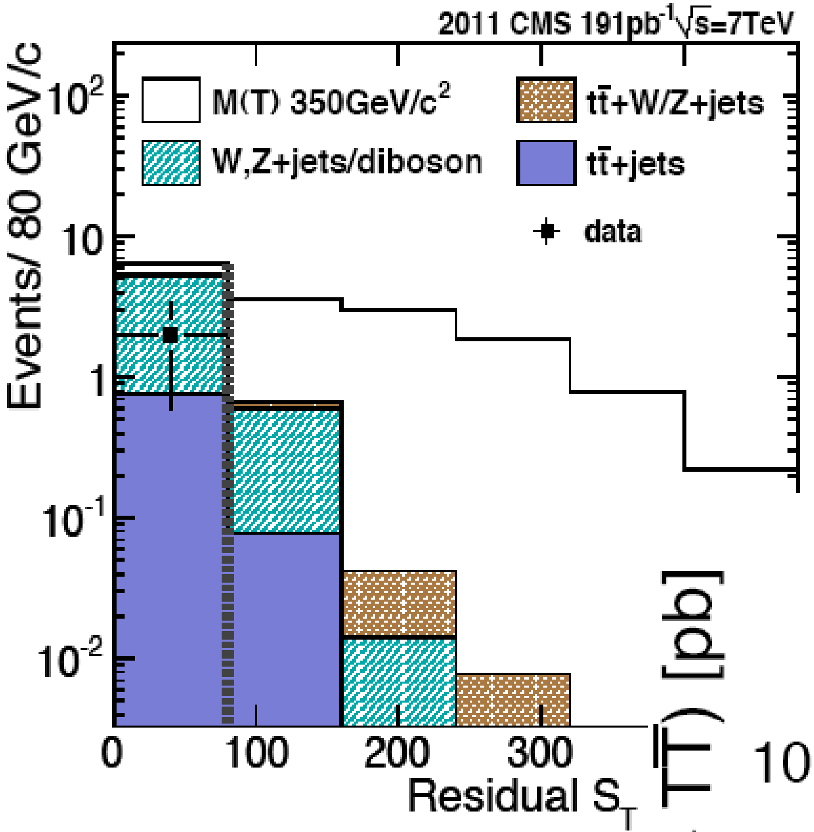


$$\tilde{g} \rightarrow \tilde{t} + t$$

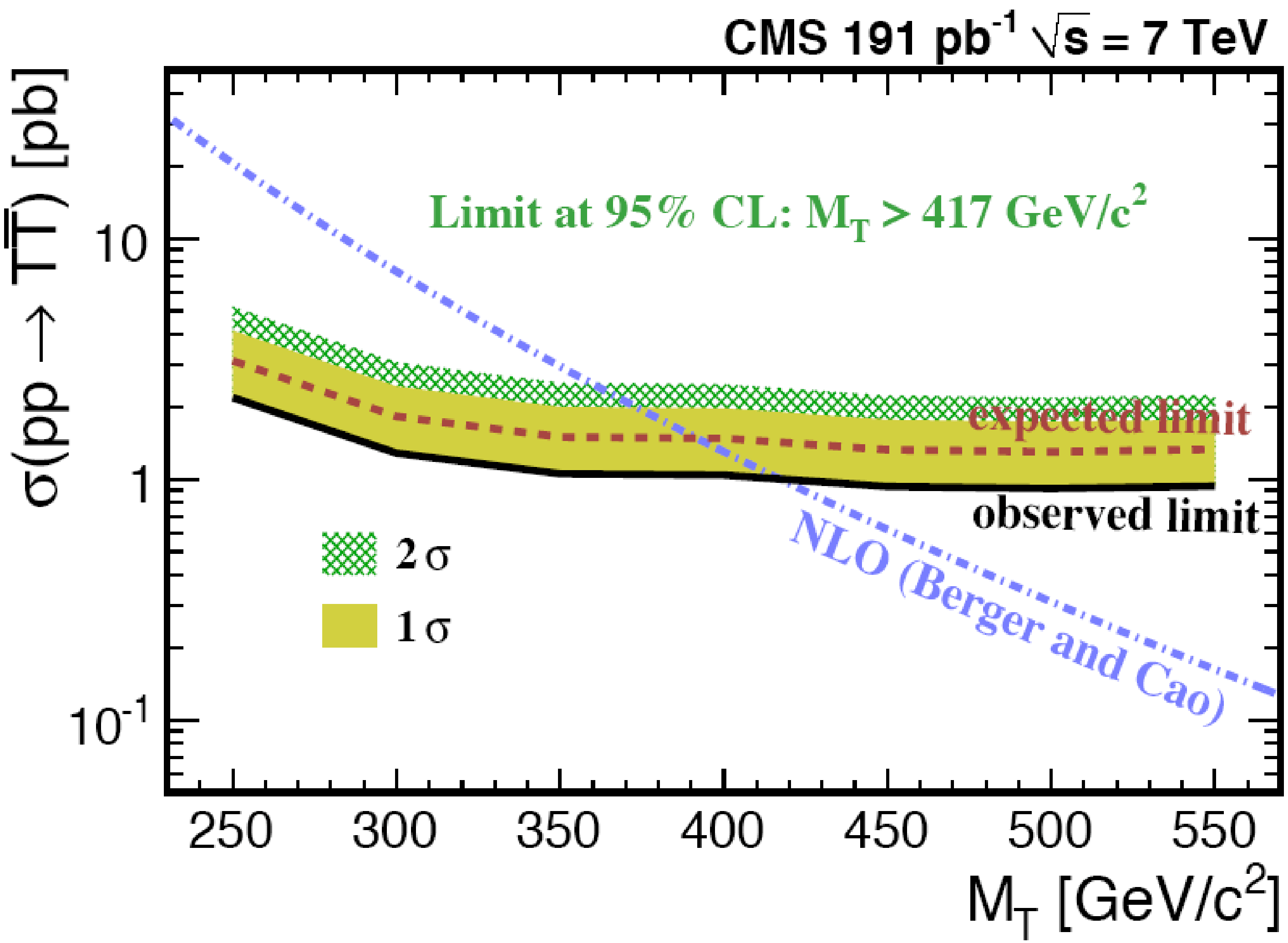


$$\tilde{g} \rightarrow \tilde{b} + b$$


CMS Preliminary $\sqrt{s}$ = 7 TeV 1091 pb^{-1}
σ (pb)
Theoretical Prediction
gluino (NLO+NLL)
stop (NLO+NLL)
GMSB stau (LO)
Tk + TOF
gluino; 50% $\tilde{g}$g
gluino; 10% $\tilde{g}$g
stop
GMSB stau
10
1
10^{-1}
10^{-2}
10^{-3}
500
1000
Mass (GeV/c^2)



current limits on
$T \to tZ^0$



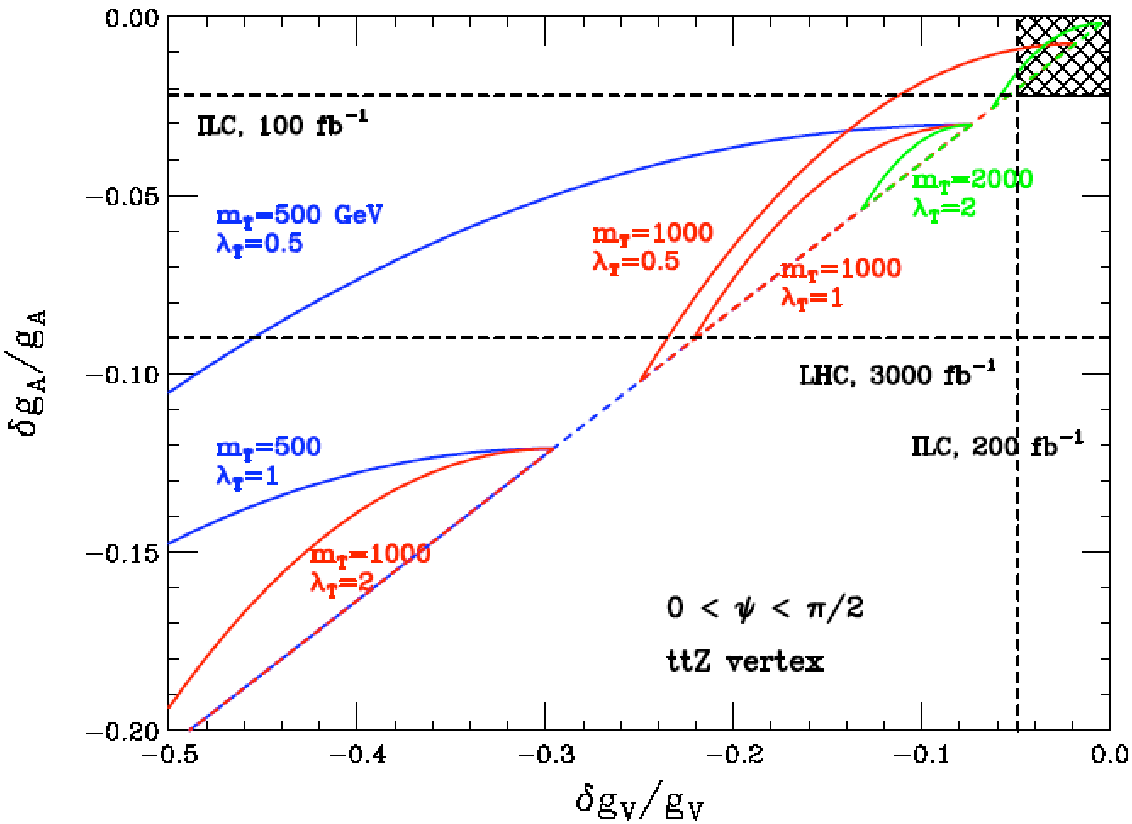
Remember also that, if no new physics is seen, the mystery of electroweak symmetry breaking does not go away. Precision probes that are available from the W and the top will become more important.

From "The Case for a 500 GeV Linear Collider" (2000):

"In the past few years, there has been a theoretical preference for supersymmetry and other weakly-coupled models of electroweak symmetry breaking. If supersymmetric particles are not discovered at the LHC, this situation will change dramatically. In that case, anomalous W and t coupling measurements at an e+e− collider will be among the most central issues in high-energy physics."

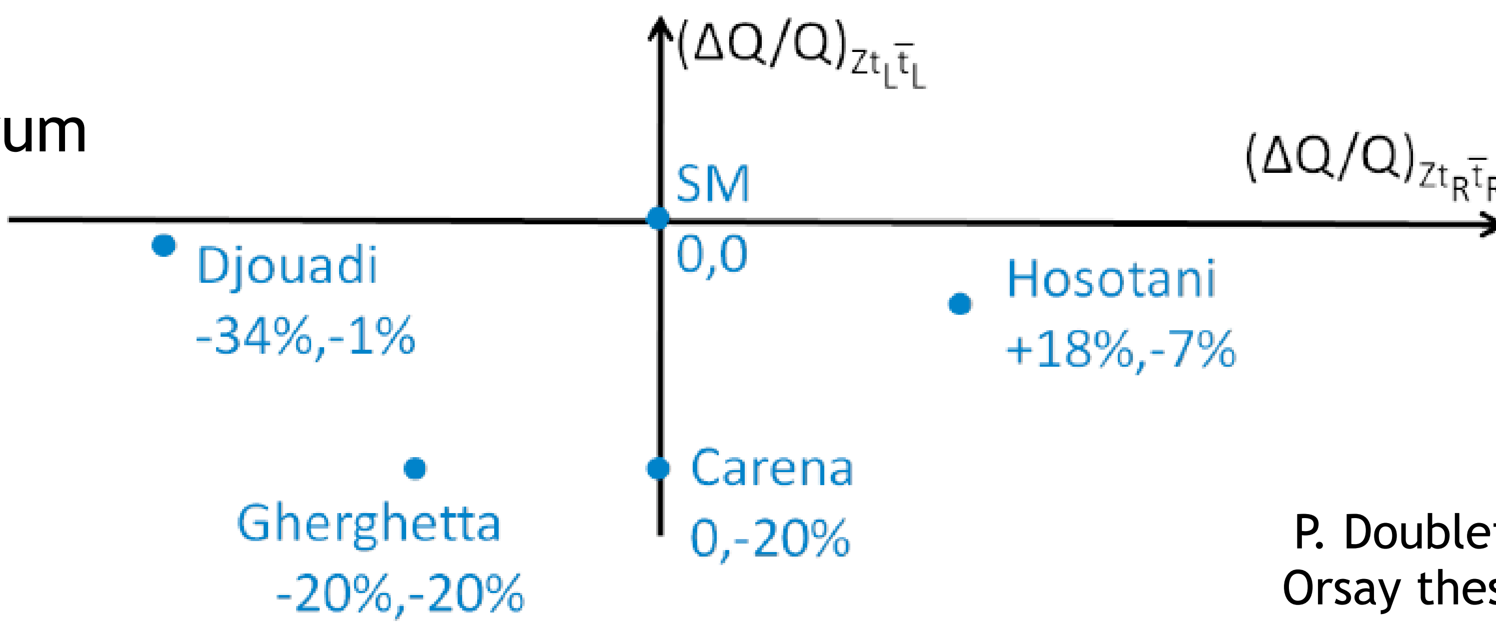
A crucial set of $Q = 0$ parameters are the top couplings to the Z. These are not accessible with precision at the LHC.

Little Higgs models



Berger, Petriello, Perelstein

Randall-Sundrum models



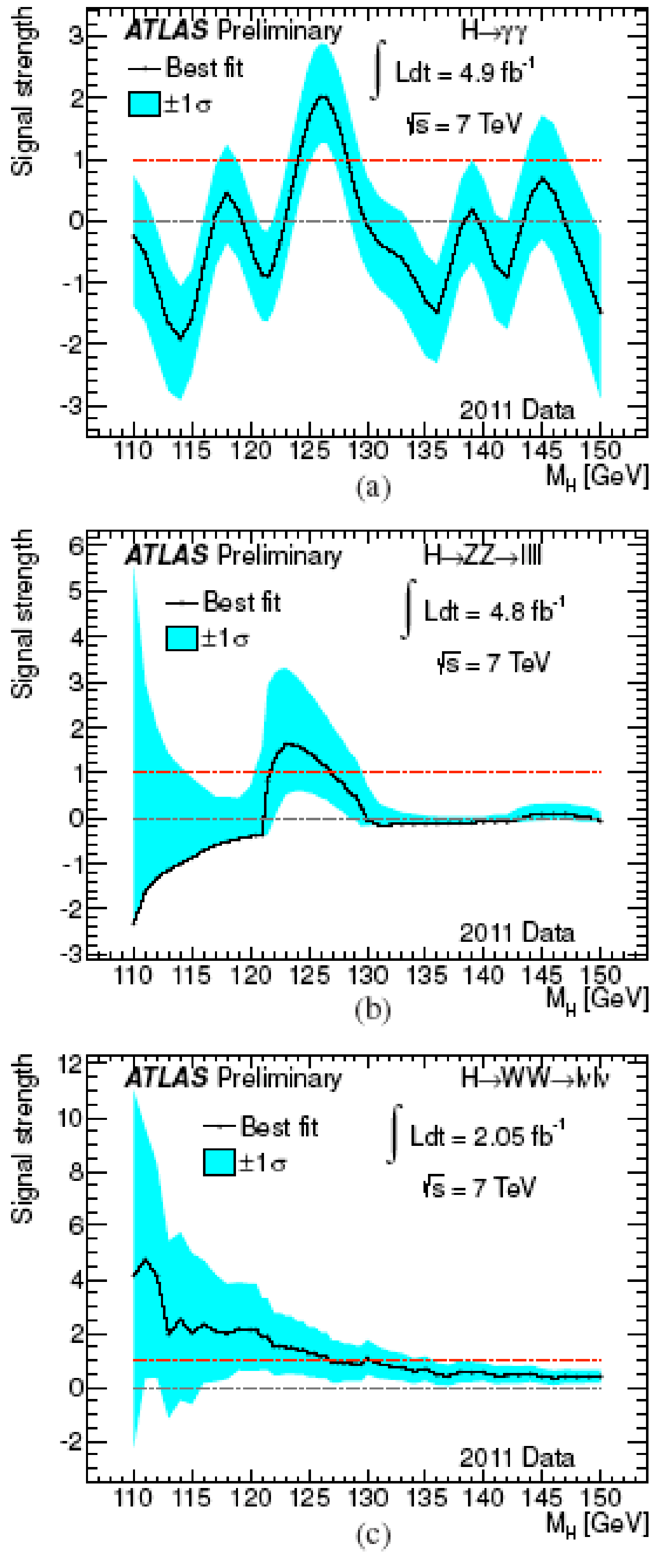
P. Doublet, Orsay thesis

Finally, discuss the Higgs. If the new indications are right and there is a Standard-Model-like Higgs resonance at 125 GeV, we will know by the end of next year (20 fb-1).

As Paul Grannis put it, "This is not bad news for the ILC."

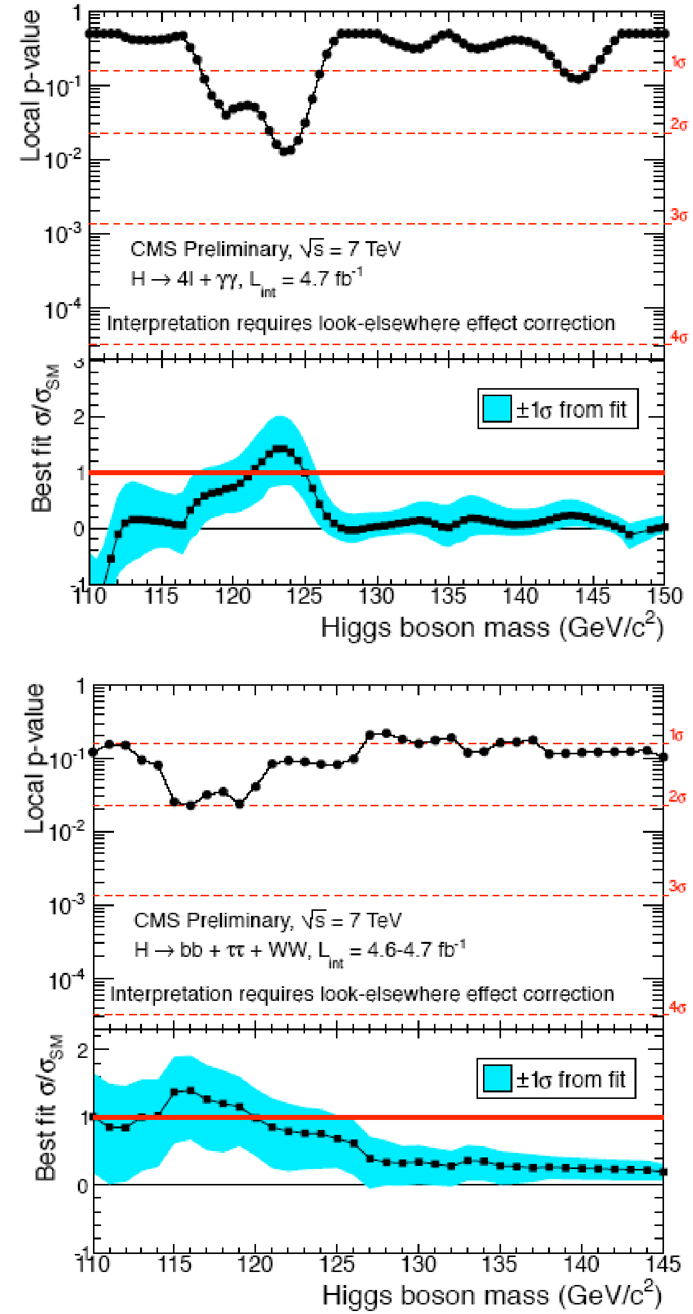
I will quickly review the current status and long-term LHC prospects.

ATLAS



ATLAS Preliminary
H→γγ
Best fit
±1σ
∫ Ldt = 4.9 fb-1
√s = 7 TeV
2011 Data
Signal strength
MH [GeV]
(a)
ATLAS Preliminary
H→ZZ→llll
Best fit
±1σ
∫ Ldt = 4.8 fb-1
√s = 7 TeV
2011 Data
Signal strength
MH [GeV]
(b)
ATLAS Preliminary
H→WW→lνlν
Best fit
±1σ
∫ Ldt = 2.05 fb-1
√s = 7 TeV
2011 Data
Signal strength
MH [GeV]
(c)

CMS



Local p-value
CMS Preliminary, √s = 7 TeV
H → 4l + γγ, Lint = 4.7 fb-1
Interpretation requires look-elsewhere effect correction
Best fit σ/σSM
±1σ from fit
Higgs boson mass (GeV/c2)
Local p-value
CMS Preliminary, √s = 7 TeV
H → bb + ττ + WW, Lint = 4.6-4.7 fb-1
Interpretation requires look-elsewhere effect correction
Best fit σ/σSM
±1σ from fit
Higgs boson mass (GeV/c2)

Key LHC measurements on the Higgs boson:

(always $\sigma \times BR$)

Gluon fusion reactions

$$pp \to h \to \gamma\gamma$$

$$pp \to h \to WW^*, ZZ^*$$

Vector boson fusion reactions

$$pp \to (VBF) + h \to \tau^+\tau^-$$

$$pp \to (VBF) + h \to WW^*, ZZ^*$$

$$pp \to (VBF) + h \to \text{ invisible}$$

Associated production

$$pp \to (W, Z) + h(\to b\bar{b})$$

$$pp \to t\bar{t} + h(\to b\bar{b})$$

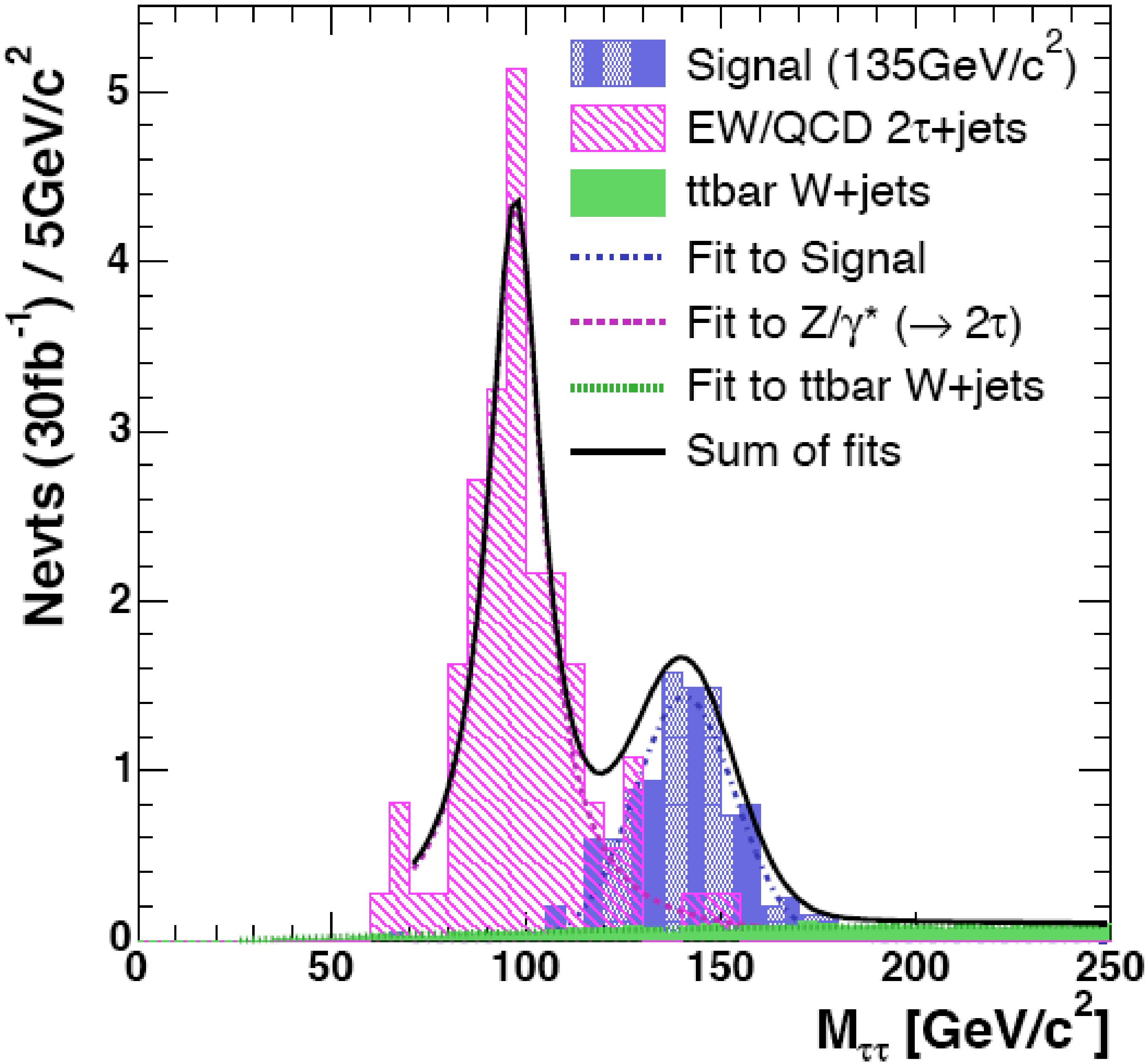
Conclusions:

Checks to 10-20% level of observable modes.

Higgs mass to 100 MeV

comments on vector boson fusion

signature: 2 jets, $\Delta y > 4$, jet veto at small $|y|$



$h \to \tau^+\tau^-$

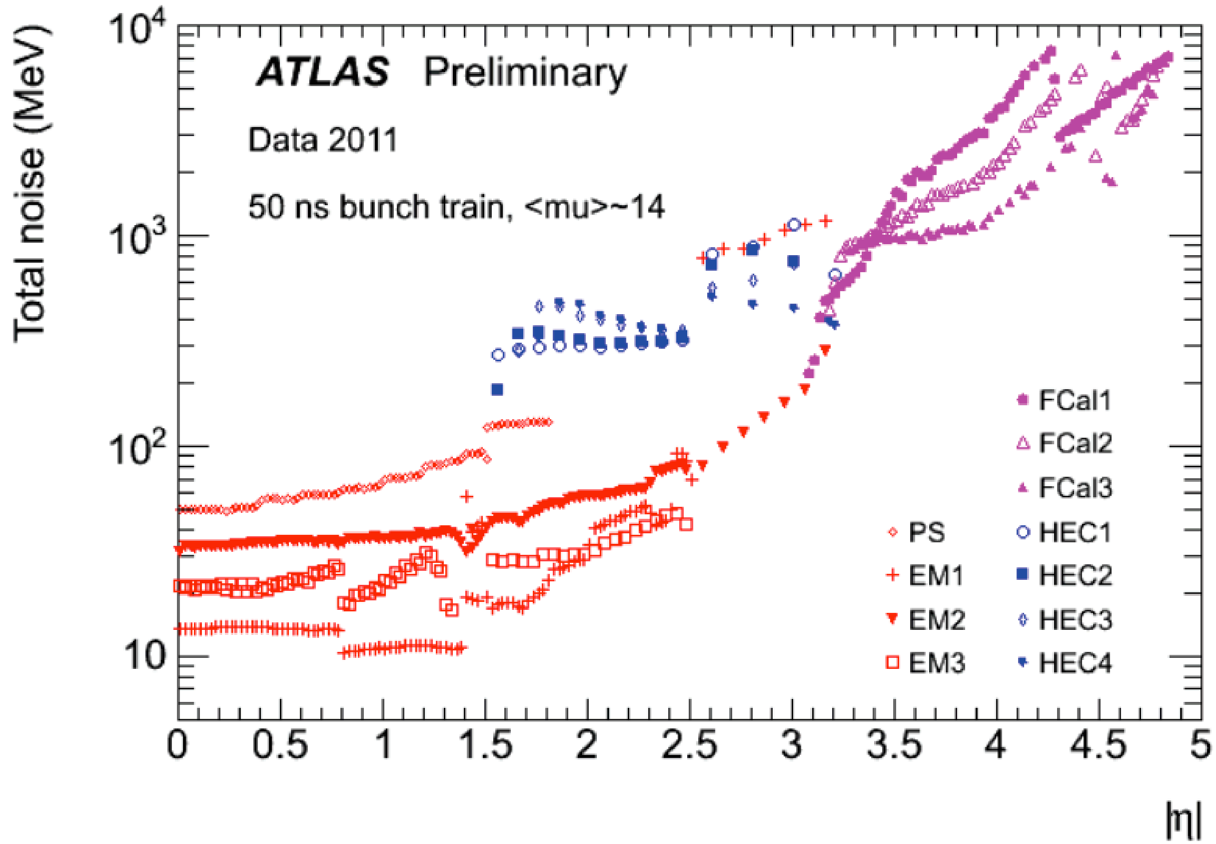
$m_h = 135$ GeV

CMS simulation

Existing studies ignore pileup. This is potentially an essential complication.

The clever method developed in the past year to ameliorate the effects of pileup rely on tracks, and thus are limited to jets at $|y| < 2$.

Pedestals and noise increase dramatically in the forward regions.

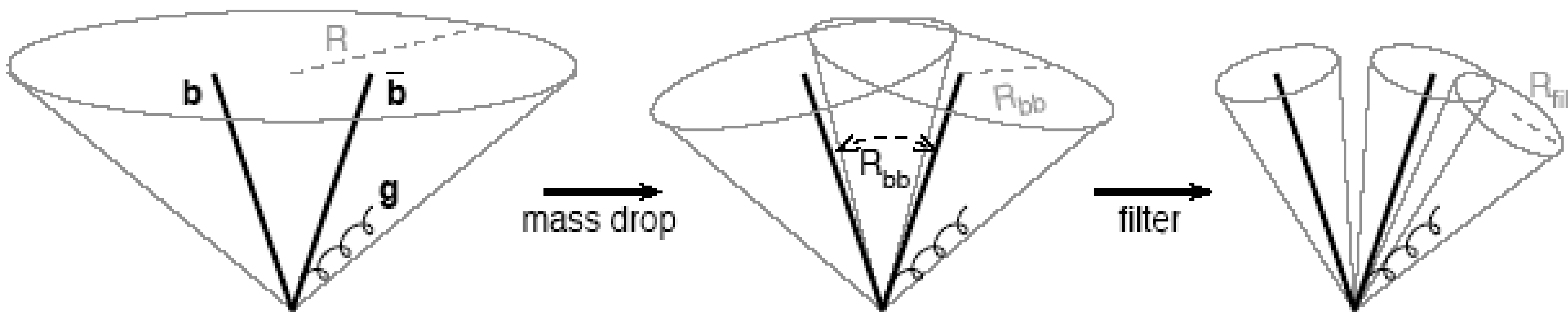


Can LHC detect the h in the dominant decay $h \to b\bar{b}$?

It is not so obvious:

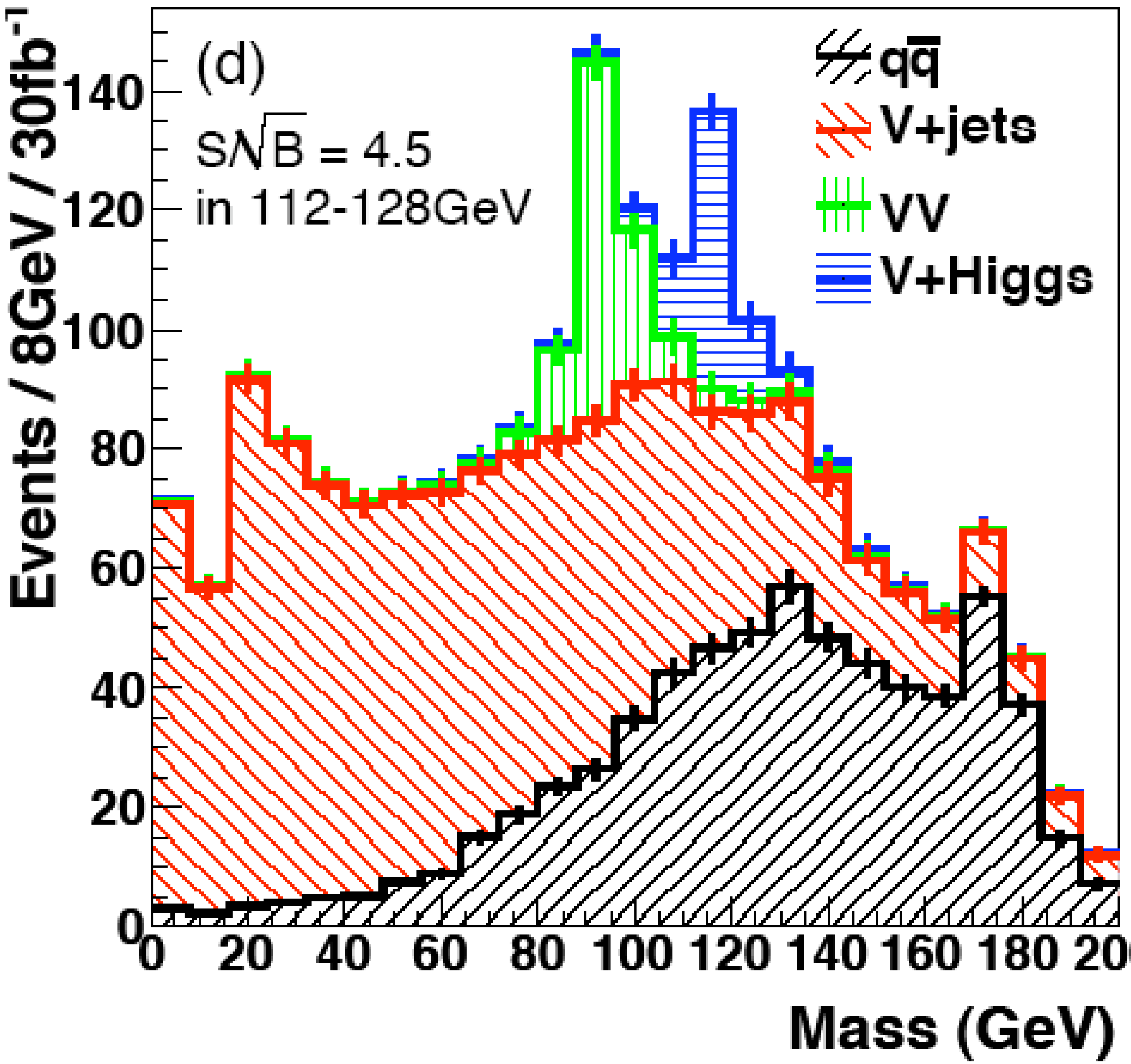
$$\sigma(pp \to h) \sim pb \ , \quad \sigma(pp \to bb(125 \text{ GeV})) \sim \mu b$$

New idea: "boosted Higgs" : Identify h as a high-pT jet with 2-b-subjet substructure. Groom the jets to remove extra radiations, underlying event and pileup.



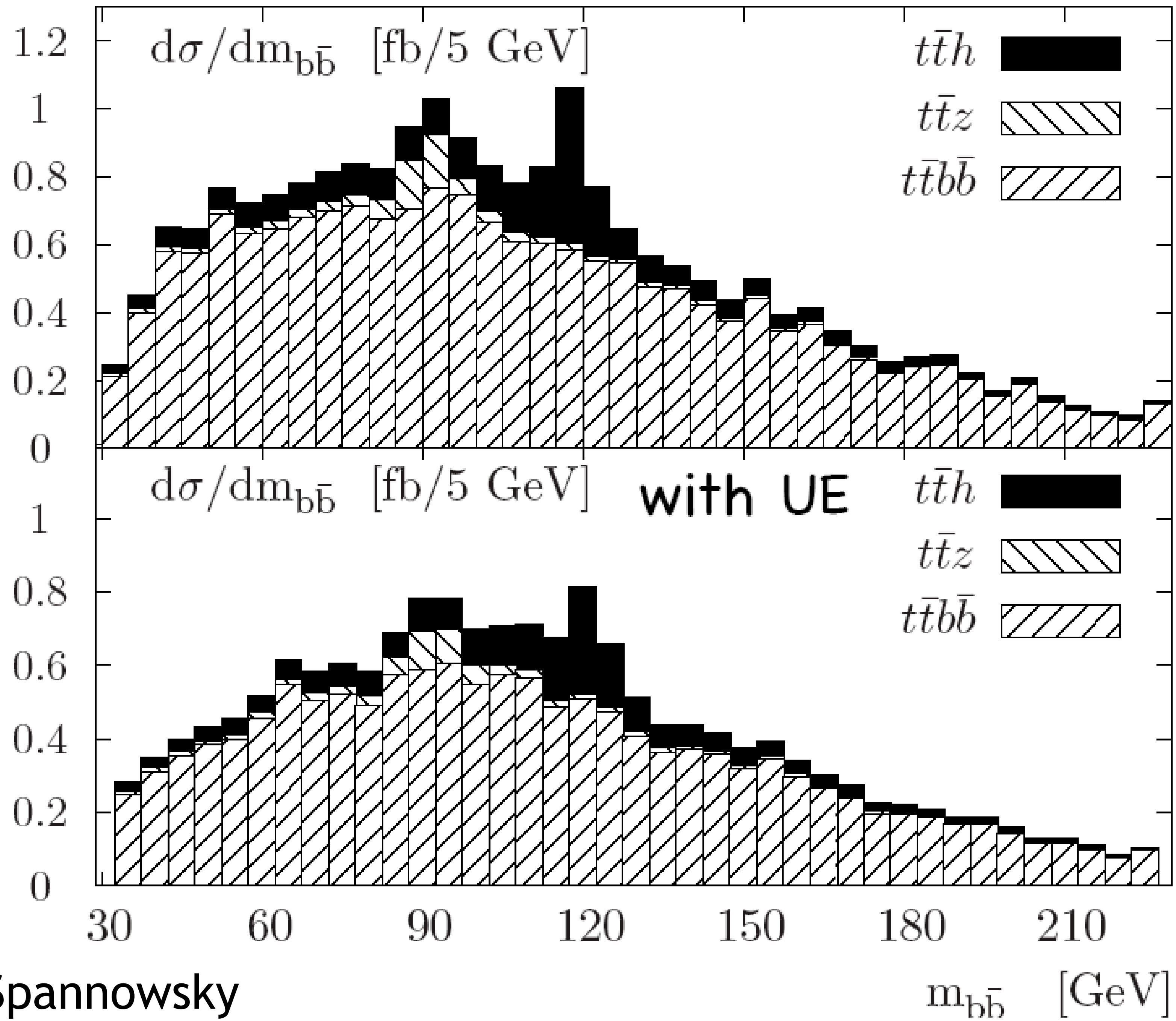
Calibration of this technique is difficult. Probably this will be based on $pp \to Z$ processes seen in parallel analyses.

$pp \to (W, Z) + h$



Butterworth, Davison, Rubin, Salam

$pp \to t\bar{t} + h(\to b\bar{b})$



Spannowsky

Why is it important to go beyond this, to the 1% level in Higgs couplings ?

Missing information:

Total width of the Higgs ? Invisible width ?

$$BR(b\bar{b})/BR(c\bar{c}) \; ? = m_b/m_c(\mu) = 4.51(4) \quad \text{(HPQCD)}$$

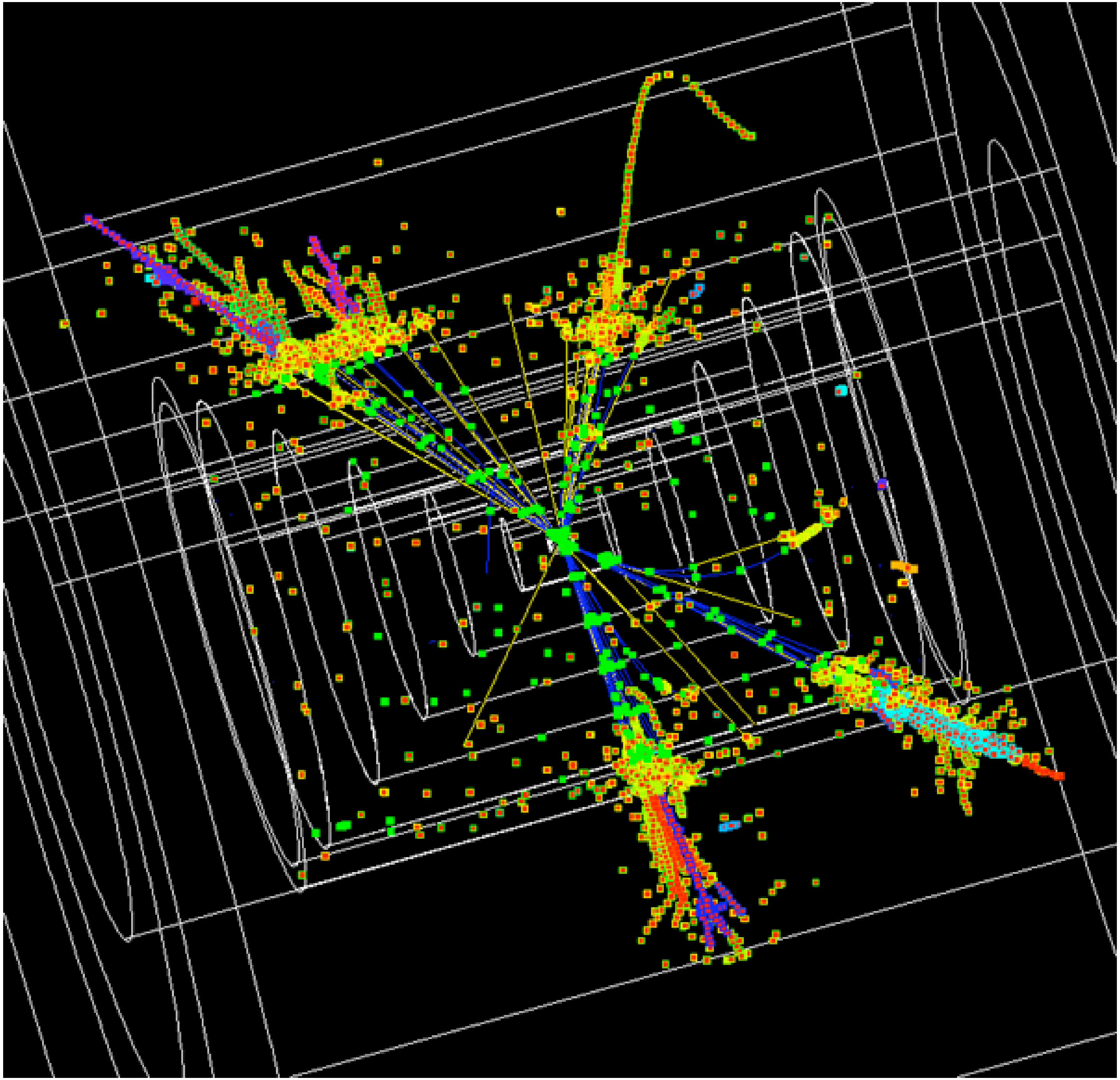
Direct observation of $h \to gg$

Questions for the 1% level:

Does the Higgs boson produce 100% of the masses of the W and Z ?

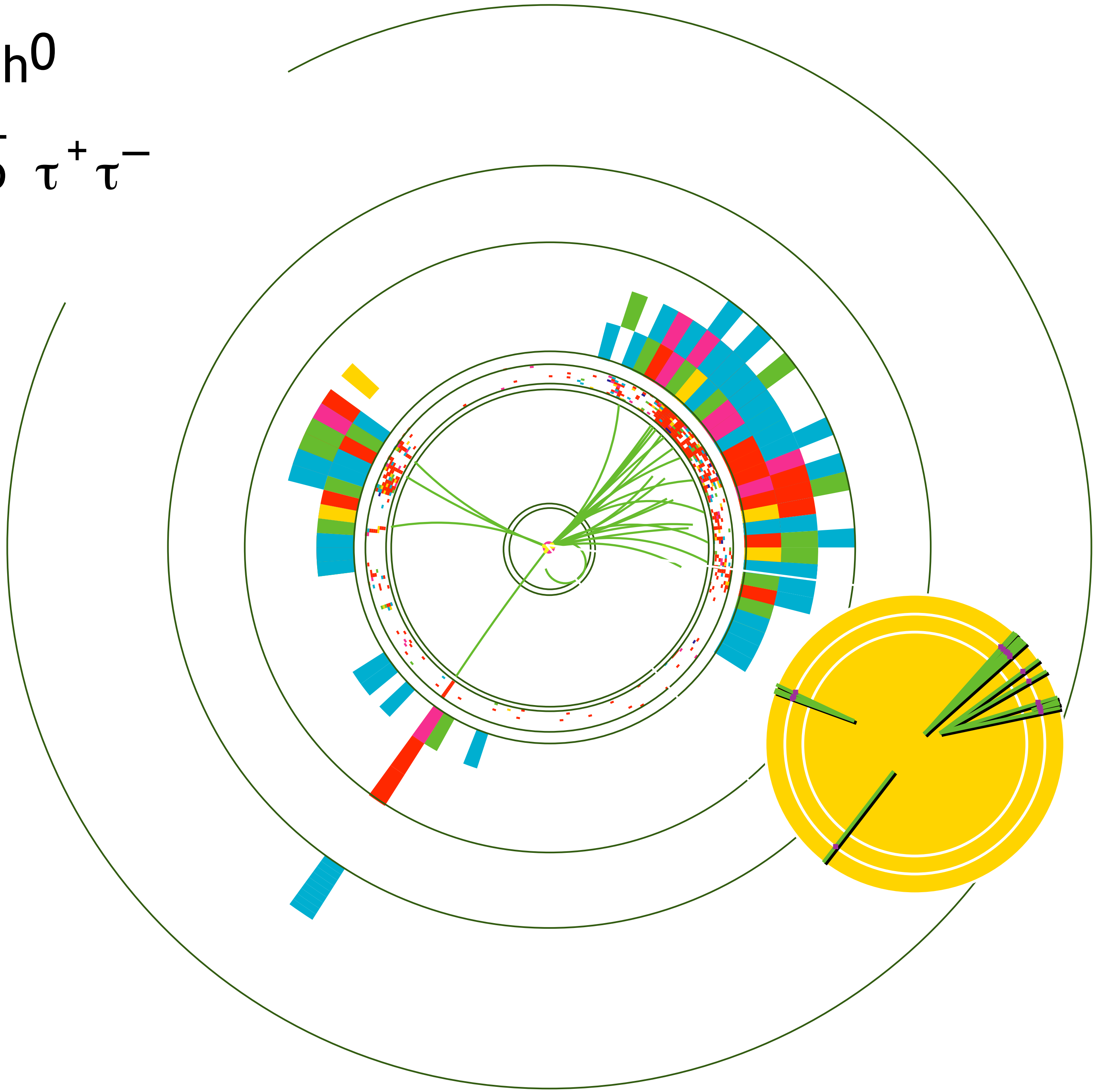
Are there different Higges that couple to different SM species?
If one Higgs is light, decoupling pushes these effects to the percent level.

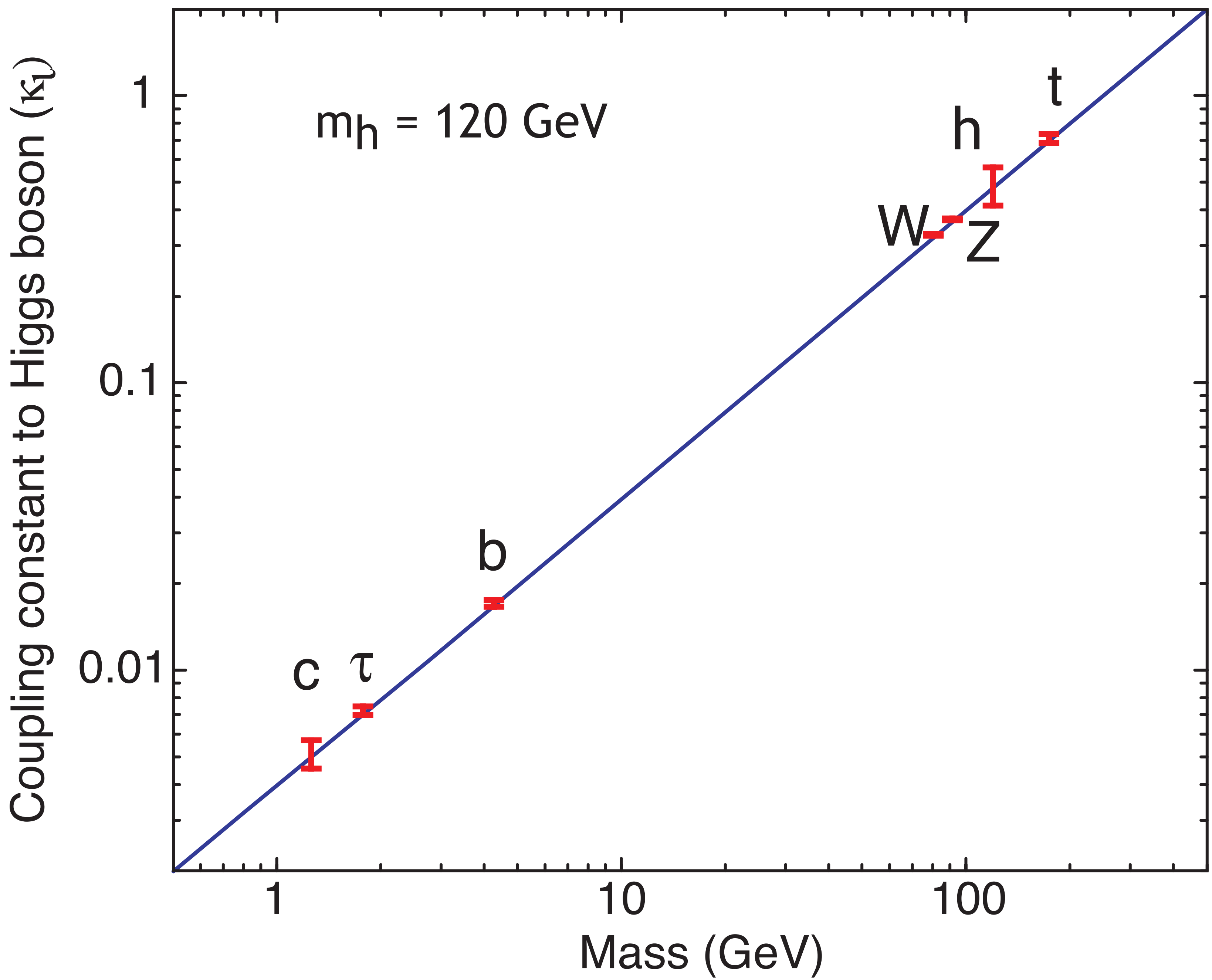
Does the Higgs mix with the radion or other possible scalar particles?



$e^+e^- \to Z^0\ h^0$

$\to b\,\bar{b}\ \tau^+\tau^-$





ACFA LC study

Is the nature of the Higgs boson the most important mystery in science ?

Yes !

So, high statistics Higgs measurements are very important.   It has become urgent to think about how to produce these Higgses.

Accelerator options for an e+e- Higgs factor at 230 GeV:

1. ILC - first stage

2. e+e- synchrotron in the LHC tunnel, with the maximum number of superconducting cavities. Luminosity = 100 x LEP 2. (CERN Higgs Factory).

3. CLIC - first stage

4. X-band linac (80 MeV/m) with klystrons; this might also be the first stage of CLIC (Xtra Compact Linear Collider).

The announcement of the Higgs discovery will be a magic time when we have the world's attention. Everyone will ask, what is next ? If the technical proposal is not ready, the moment is lost.

my conclusions:

1. The case for the ILC is still compelling.

2. The full story from LHC will not be available for many years.
   We might have to make the decision on the next collider
   with incomplete information. (What's new about that?)

3. We are going to lose a lot of sleep in 2012.

4. We hope for a Merry Christmas -- next year !