Physics benchmarks for the SLHC

Atlas and CMS Electronics Workshop
March 19 2007

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For more details see:
F. Gianotti et al, Eur.Phys.J.C39:293-333,2005, http://arxiv.org/pdf/hep-ph/0204087
D. Denegri, presentation at HHH 04:
http://care-hhh.web.cern.ch/CARE-HHH/HHH-2004/default.html

Why will we need more integrated luminosity after the LHC?

1. Improve measurements of new phenomena seen at the LHC. E.g.
   - Higgs couplings and self-couplings
   - Properties of SUSY particles (mass, decay BR's, etc)
   - Couplings of new Z' or W' gauge bosons (e.g. L-R symmetry restoration?)
2. Detect/search low-rate phenomena inaccessible at the LHC. E.g.:
   - $H \to \mu^+\mu^-$, $H \to Z\gamma$
   - top quark FCNCs
3. Push sensitivity to new high-mass scales. E.g.
   - New forces (Z', W_R)
   - Quark substructure
   - ....

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Energies/masses in the few-100 GeV range. Detector performance at SLHC should equal (or improve) in absolute terms the one at LHC

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Examples: Higgs

IF SM, then the Higgs boson will be seen with $\int L \leq 15\ fb^{-1}$

- SM production and decay rates well known
- Detector performance for SM channels well understood
- $115 < m_H < 200$ from LEP and EW fits in the SM

IF seen with SM production/decay rates, but outside SM mass range:

- new physics to explain EW fits, or
- problems with LEP/SLD data

In either case,

- easy prey with low luminosity up to ~ 800 GeV, but more lum is needed to understand why it does not fit in the SM mass range!

IF NOT SEEN UP TO m_H ~ 0.8-1 TeV GEV:

$\sigma < \sigma_{SM}$: $\Rightarrow$ new physics

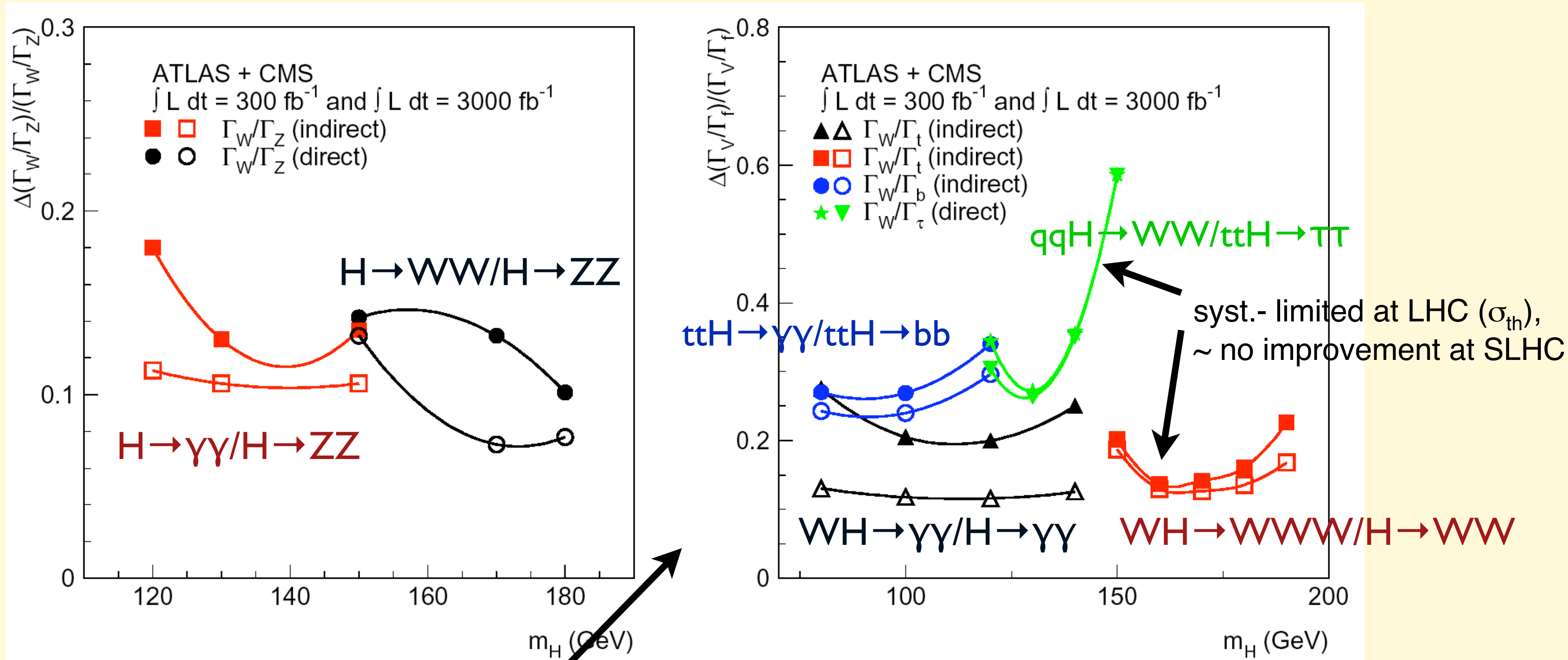
or

$BR(H\rightarrow visible) < BR_{SM}$: $\Rightarrow$ new physics

or

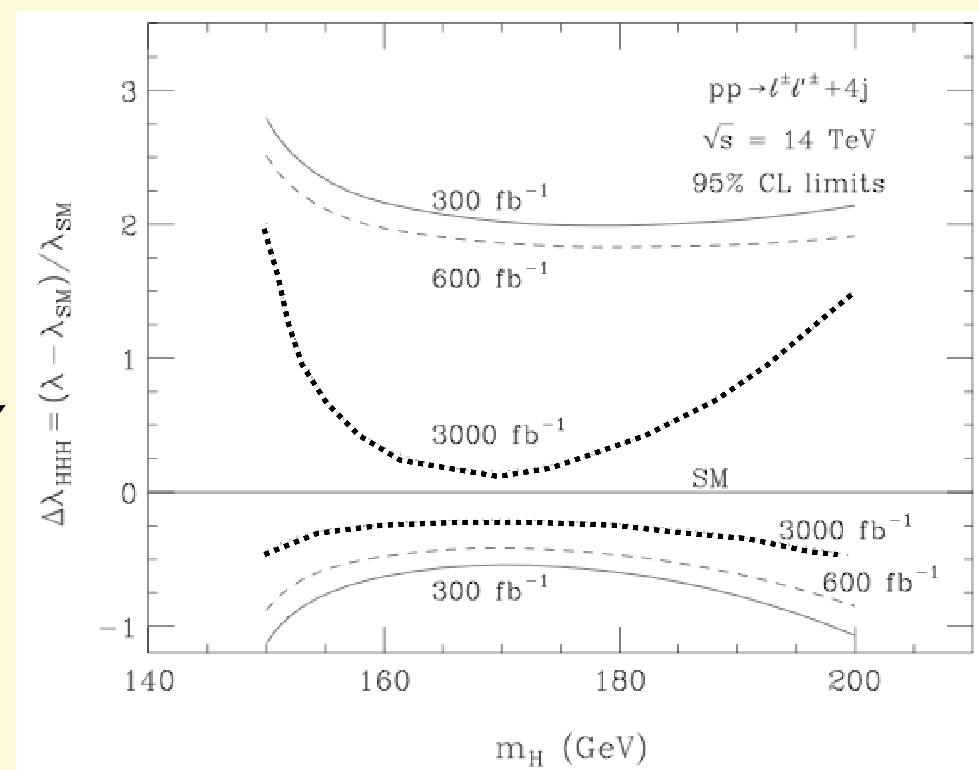
m_H>800 GeV: expect WW/ZZ resonances at $\sqrt{s}$ ~ TeV $\Rightarrow$ **new physics**

Sorting out these scenarios will take longer than the SM H observation, and may well require SLHC luminosities

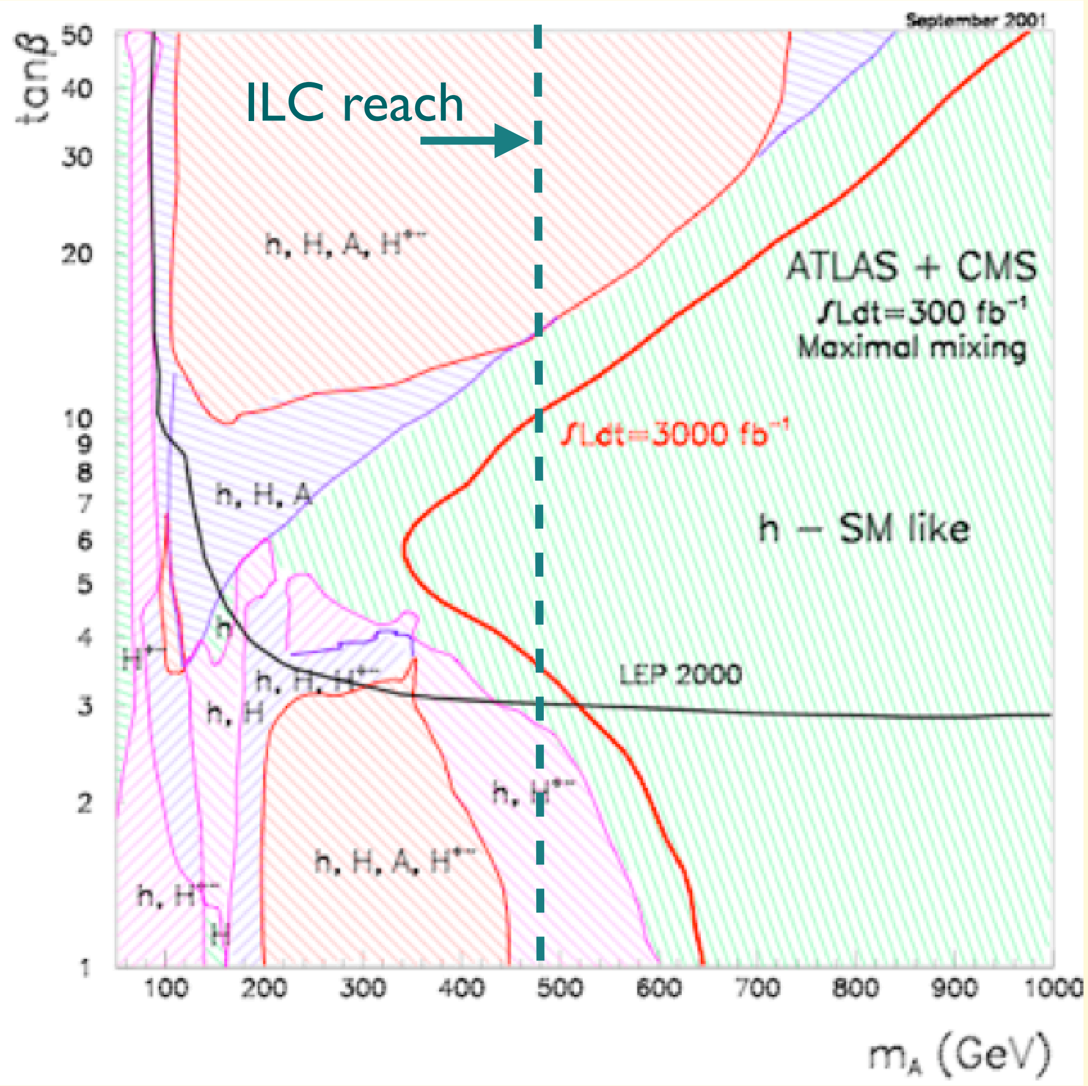


Higgs boson couplings to fermions and gauge bosons

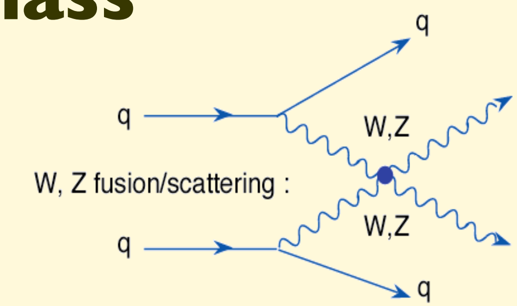
Higgs boson selfcouplings

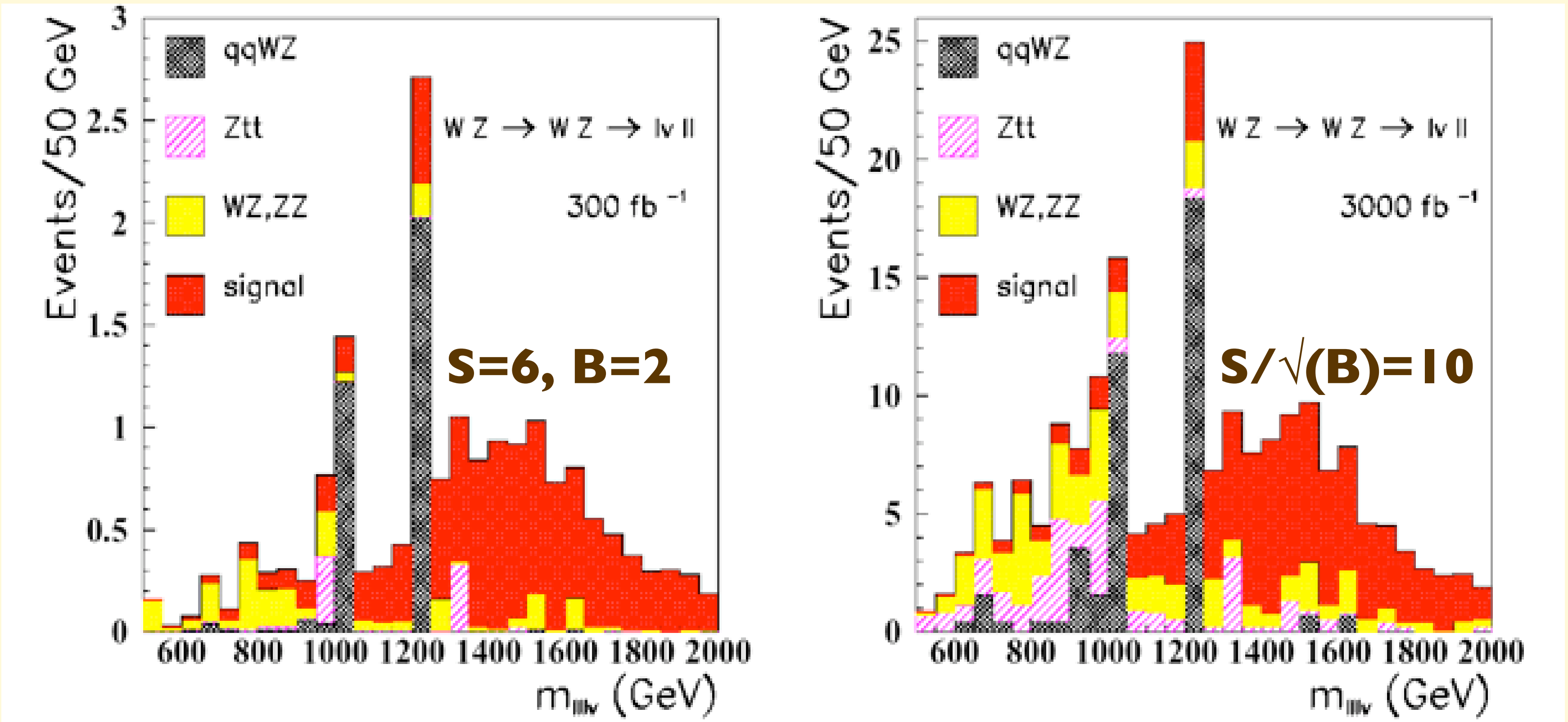


Detecting the presence of extra H particles (as expected in SUSY)



Strong resonances in high-mass WW or WZ scattering

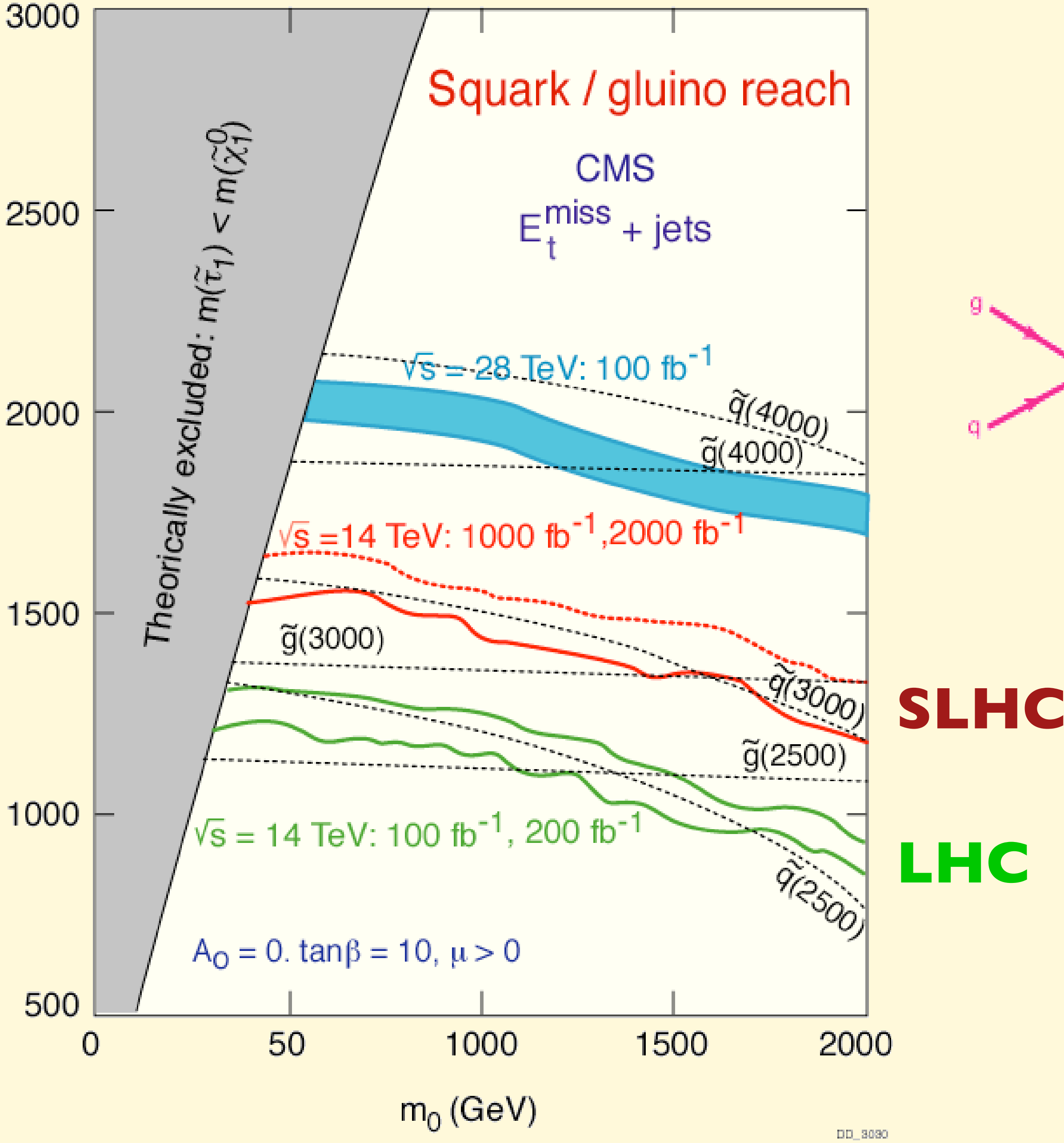


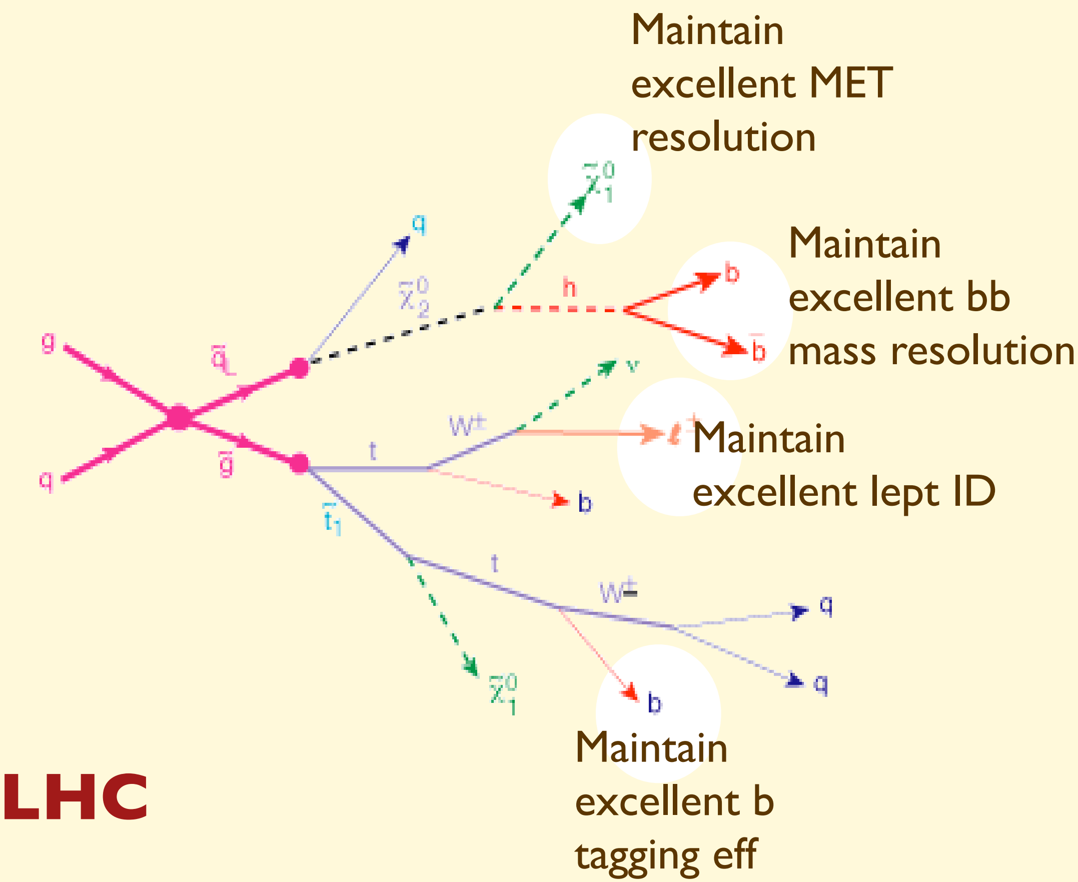


Vector resonance (ρ-like) in $W_L Z_L$ scattering from Chiral Lagrangian model
M = 1.5 TeV, leptonic final states, 300 fb^{-1} (LHC) vs 3000 fb^{-1} (SLHC)

Examples: SUSY

SUSY reach and studies



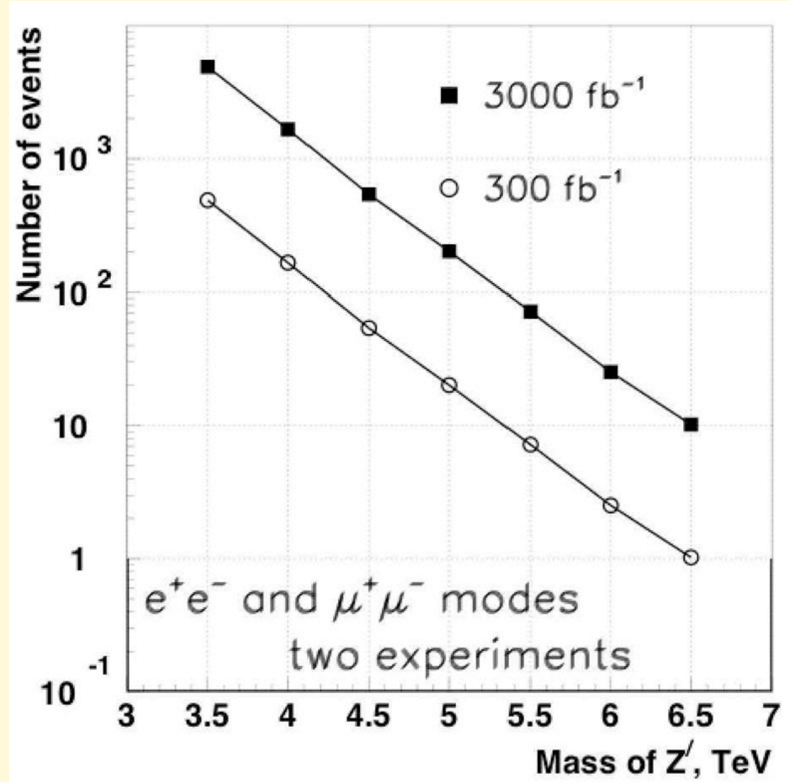


High momentum leptons, but lot of stat needed to reconstruct sparticle mass peaks from edge regions!
SLHC luminosity should be crucial, but also need for jets, b-tagging, missing E_t i.e. adequate detector performances (calorimetry, tracker) to really exploit the potential of increased statistics at SLHC…..

Examples: new weak forces

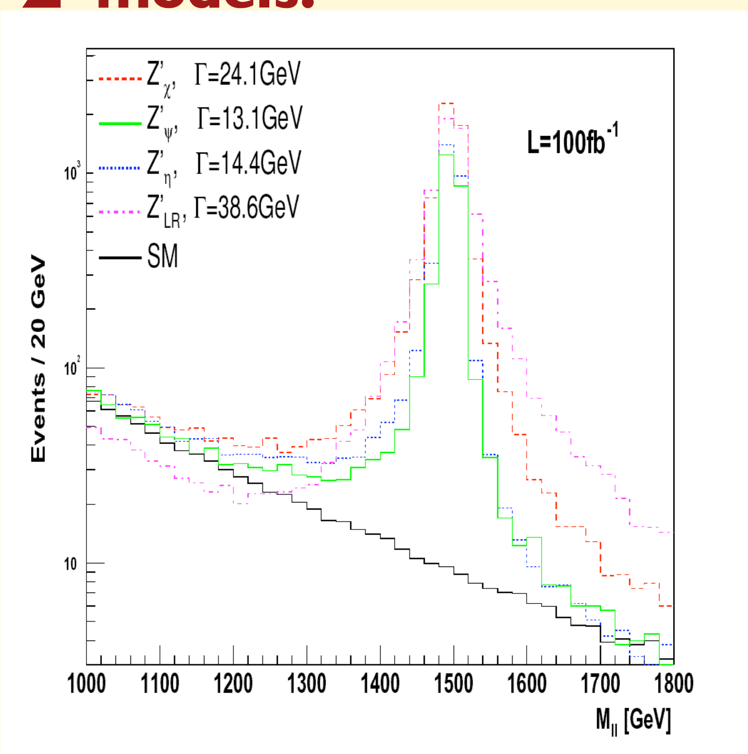
Searching new forces: W', Z'

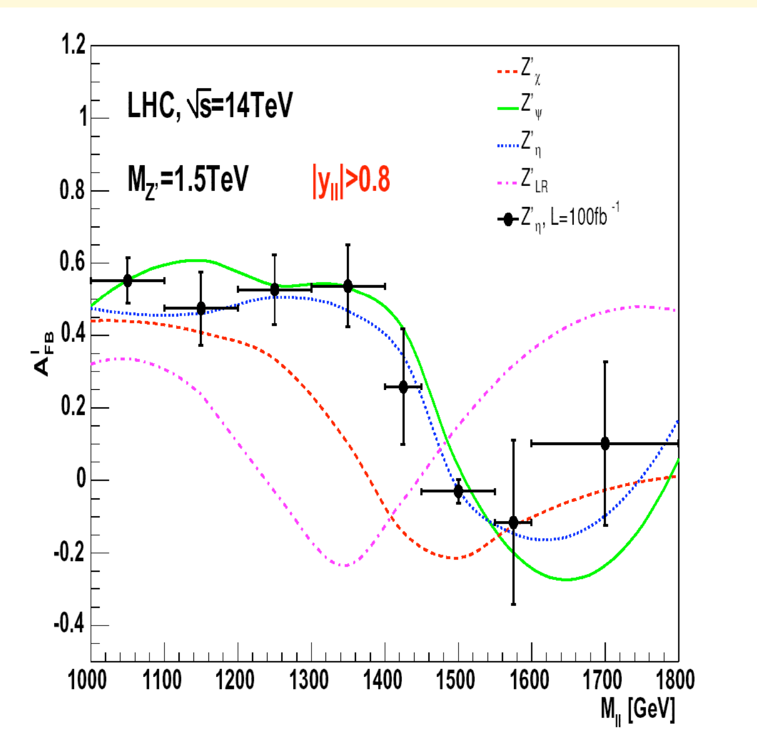
E.g. a W' coupling to R-handed fermions, to reestablish at high energy the R/L symmetry



100 fb^{-1} discovery reach up to ~ 5.5 TeV

Differentiating among different Z' models:



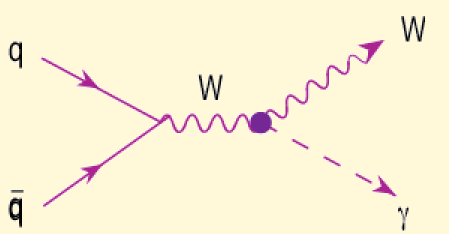


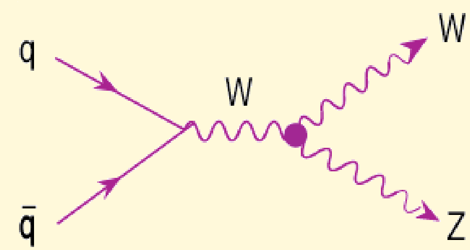
100 fb^{-1} model discrimination up to 2.5 TeV

Examples: precision EW physics

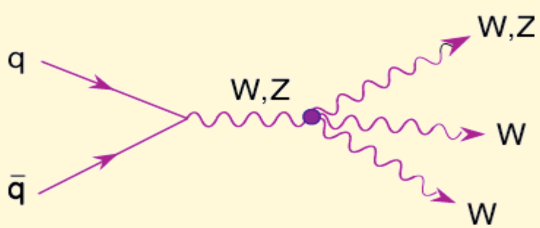
Ex: Precise determinations of the self-couplings of EW gauge bosons

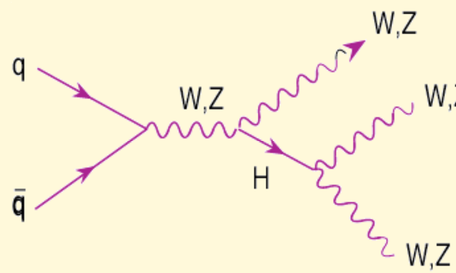
5 parameters describing weak and EM dipole and quadrupole moments of gauge bosons. The SM predicts their value with accuracies at the level of 10^{-3}, which is therefore the goal of the required experimental precision

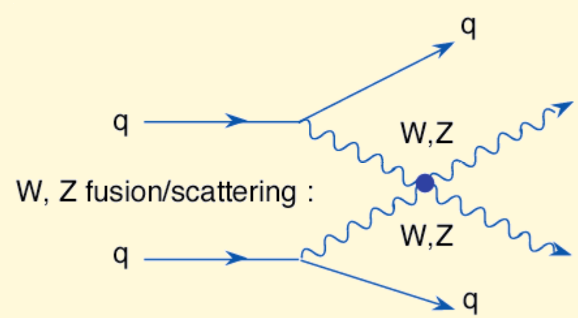




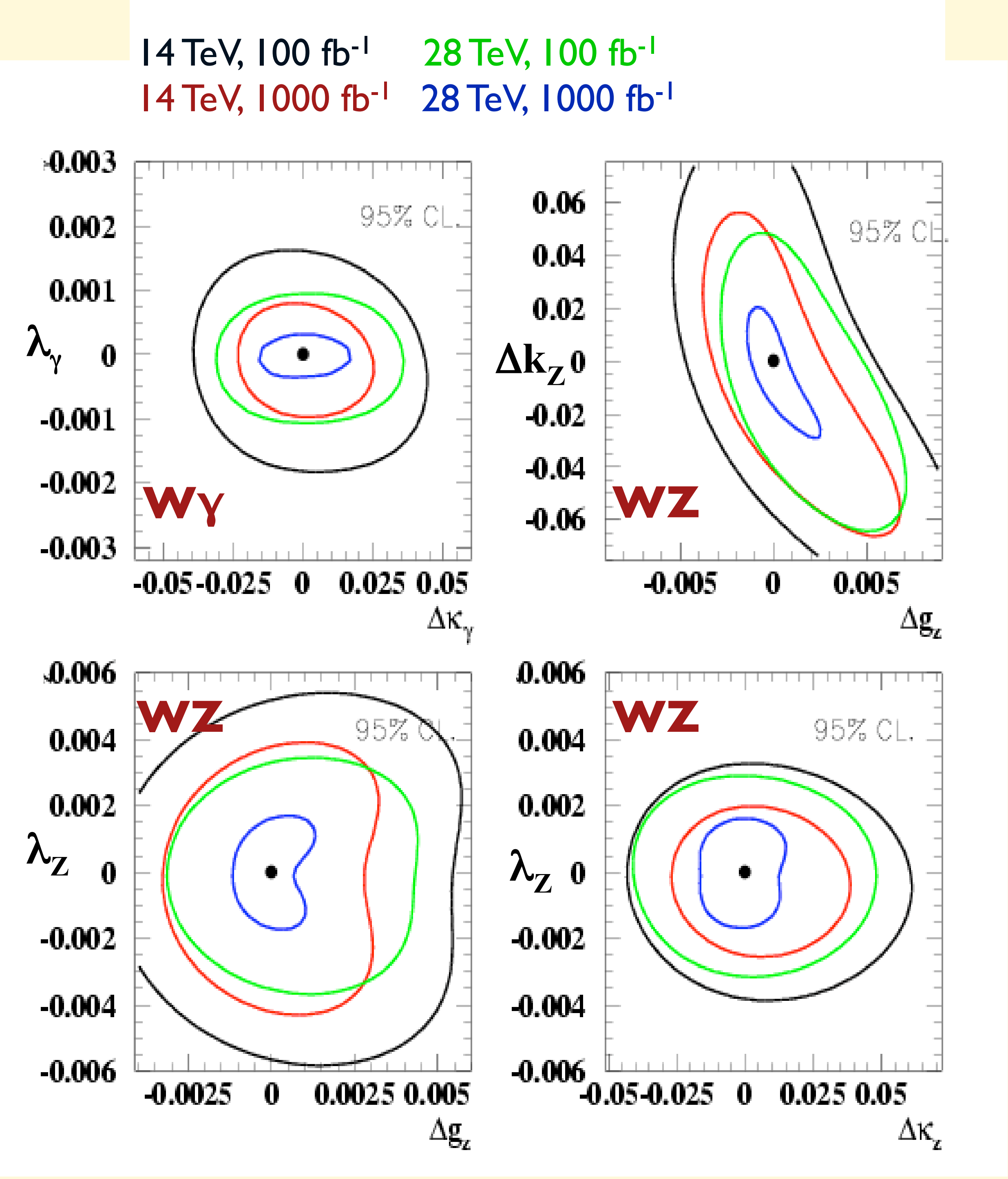
Coupling	14 TeV 100 fb^{-1}	14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	28 TeV 1000 fb^{-1}	LC 500 fb^{-1}, 500 GeV
λ_γ	0.0014	0.0006	0.0008	0.0002	0.0014
λ_Z	0.0028	0.0018	0.0023	0.009	0.0013
$\Delta\kappa_\gamma$	0.034	0.020	0.027	0.013	0.0010
$\Delta\kappa_Z$	0.040	0.034	0.036	0.013	0.0016
g^Z_1	0.0038	0.0024	0.0023	0.0007	0.0050







(LO rates, CTEQ5M, k ~ 1.5 expected for these final states)						
Process	*WWW*	*WWZ*	*ZZW*	*ZZZ*	*WWWW*	*WWWZ*
$N(m_H = 120$ GeV$)$	2600	1100	36	7	5	0.8
$N(m_H = 200$GeV$)$	7100	2000	130	33	20	1.6


14 TeV, 100 fb-1
28 TeV, 100 fb-1
14 TeV, 1000 fb-1
28 TeV, 1000 fb-1
95% CL
Wγ
WZ
WZ
WZ
λγ
Δκγ
Δkz
Δgz
λZ
Δgz
λZ
Δκz
0.003
0.002
0.001
0
-0.001
-0.002
-0.003
-0.05 -0.025 0 0.025 0.05
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.005 0 0.005
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.0025 0 0.0025 0.005
-0.05 -0.025 0 0.025 0.05

Key ingredients to benchmark performance

The performance at 10^{34} should be taken as a minimal reference goal

Object	Physics benchmark	Performance benchmark	Detector issue
b jets & tau	Higgs identification, BR measurements	Tagging efficiency vs purity (statistics and bg suppression)	Tracking Pileup
b jets	Higgs mass determination, bg suppression	Mass resolution in the ~ 1-few x 100 GeV region	Pileup
fwd jets	Vector boson fusion: - measure H couplings - if no H, search strong WW phenomena	- jet tagging efficiency/fake rate vs jet E_T - jet E_T resolution	Final focus magnets: - acceptance - bg - resolution Pileup
cen jets	Jet vetoes for vector boson fusion	fake rate	Pileup
	Mass spectroscopy	mass resolution	Pileup
electrons	W/Z ID, SUSY decays, etc W'/Z' properties	ID efficiency vs fake rate	Pileup
muons	W/Z ID, SUSY and H decays, W'/Z' properties, etc.	Forward acceptance, fake rate	albedo forward efficiency final focus geometry

Physics performance benchmarks:

I) Higgs studies:
  a) H couplings and selfcouplings
  b) WW scattering and resonances

II) SUSY spectroscopy:
- what's the added value of the SLHC, relative to the LHC, for low-mass SUSY (O(TeV))? Consider mass reconstruction, sparticle ID, BR measurements, etc.
- performance for heavy SUSY (say > 2 TeV) (impact of statistics)

III) EW physics:
- boson selfcouplings: concentrate of those for which the SLHC could achieve sensitivity competitive with the ILC.

IV) Superheavy stuff
- in principle one would expect that for very heavy objects either scenario is equivalent. It would be nice to prove this (or to look for unexpected efects), considering e.g. the case of little Higgs scenarios, with T, W' and Z/ objects in the multi-tev region.

Comment: Optimize (lum x performance):

A better detector at lower lum could be preferable to higher lum and a lesser performing instrument

The process*

- Develop/update/upgrade simulation tools and environment:
  - machine final-focus elements in the detector geometry:
    - albedo bgs
    - calorimetric acceptance/resolution a small angle
  - tracking simulations
    - evaluate different layouts for new trackers
  - ...
- Timescale
  - ~ 1 month for fast simulations
  - ~ 6 months for full G4
- Organize an open 1-day workshop

* G.Rolandi, D.Denegri, N.Hessey, E.Tsemelis, M.Mangano, for POFPA+ATLAS+CMS

From R. Orbach (DoE Undersecretary)
remarks to HEPAP, Febr 22 2007:

"Even assuming a positive decision to build an ILC, the schedules will almost certainly be lengthier than the optimistic projections. Completing the R&D and engineering design, negotiating an international structure, selecting a site, obtaining firm financial commitments, and building the machine could take us well into the **mid-2020s, if not later**."

$\Rightarrow$ the burden of exploring and measuring the properties of

phenomena at the high-energy frontier will rest with the LHC for a long long time!