Physics at the LHC: status and prospects, in view of the upgrade

HighLumi LHC / LARP Collaboration meeting

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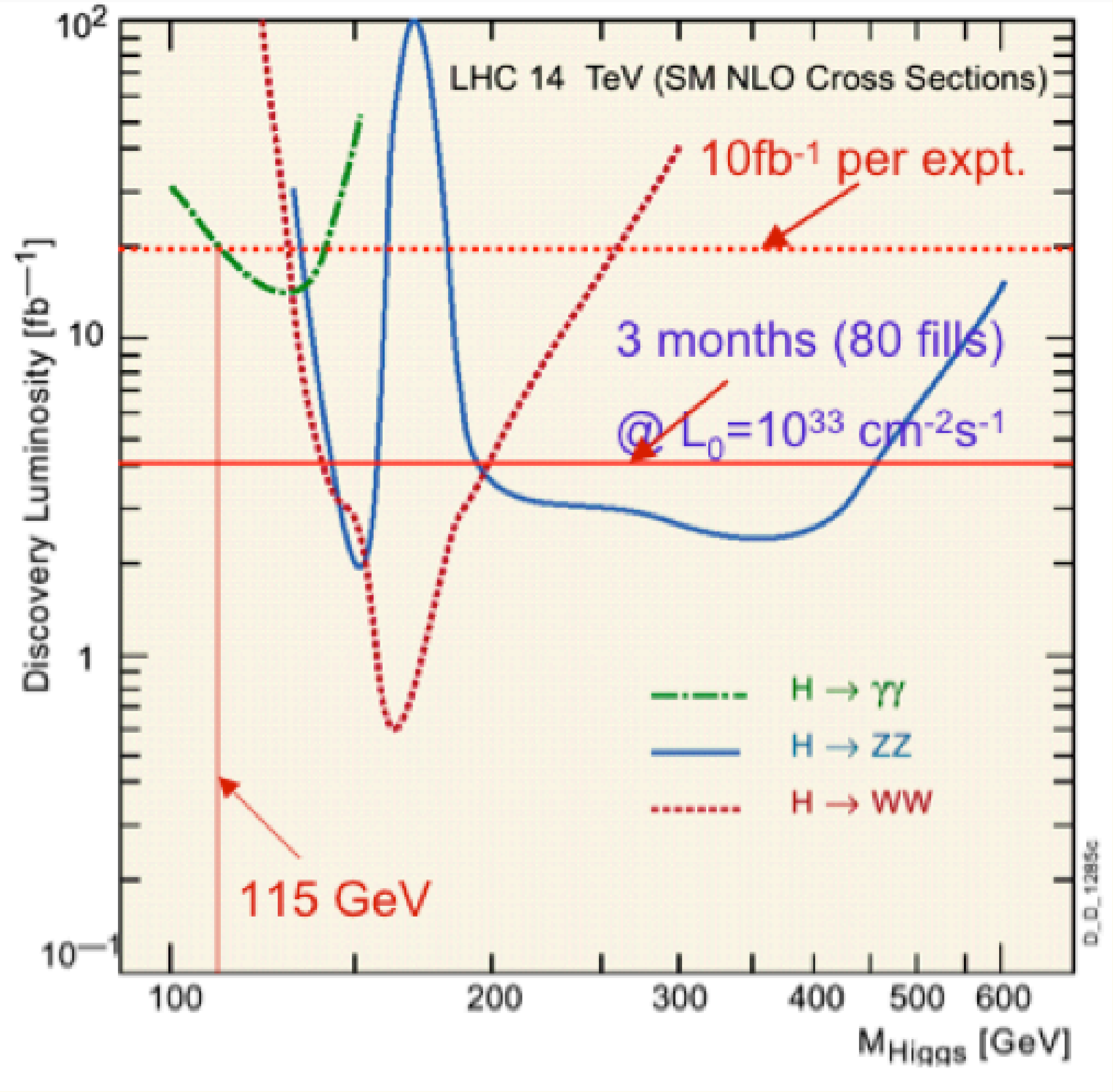
The crucial question, with a mandate to answer it, from Lucio:

If we don't find the Higgs, is it still worth to upgrade the LHC luminosity?

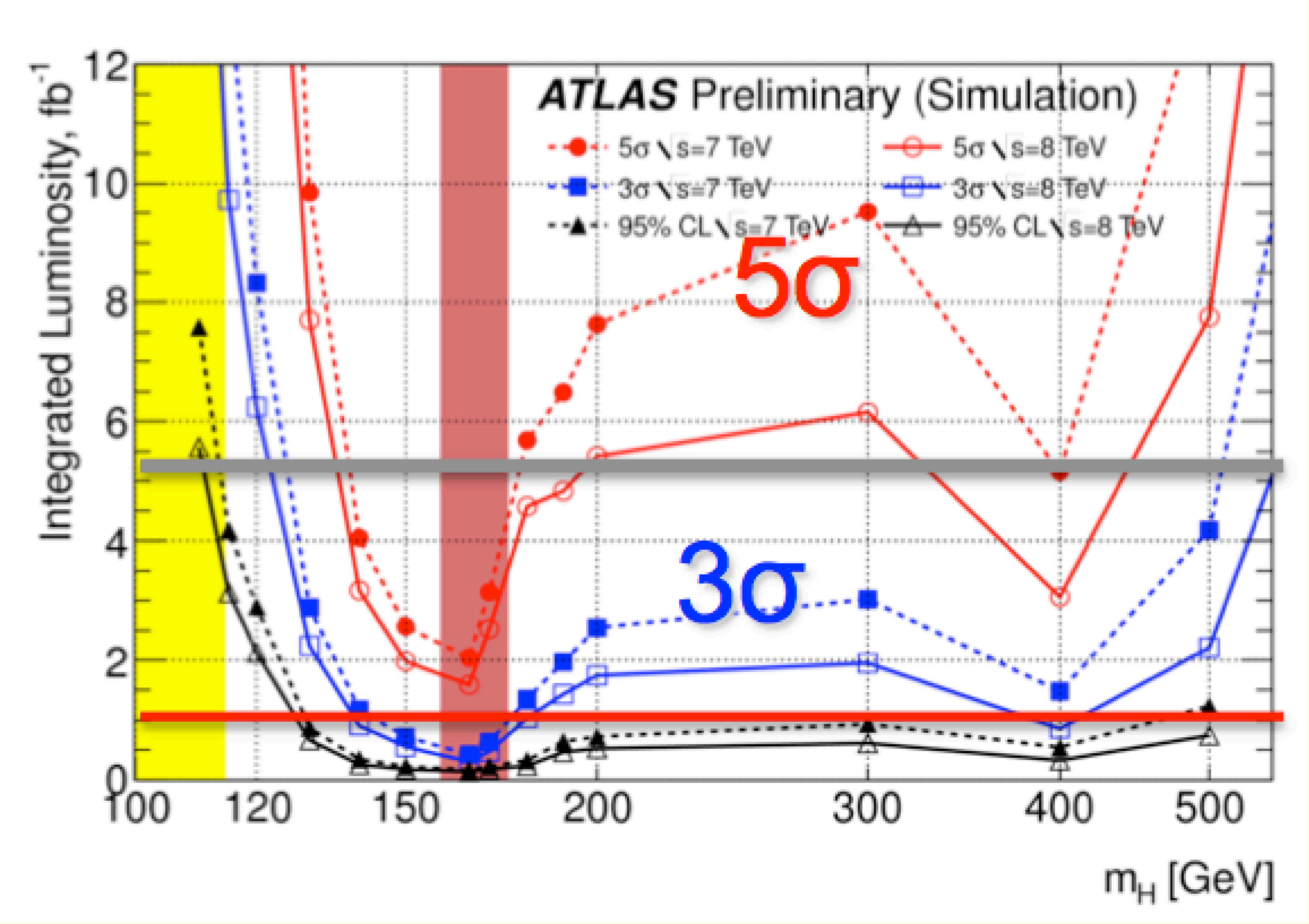
A typical pre-2009 Higgs-discovery prospects plot:



– 10 fb^{-1}/expt at 14 TeV needed to cover the low-mass region (*~30 fb^{-1} at 7 TeV*)

– much more needed to explore the very high mass region (*out of reach at 7 TeV*)

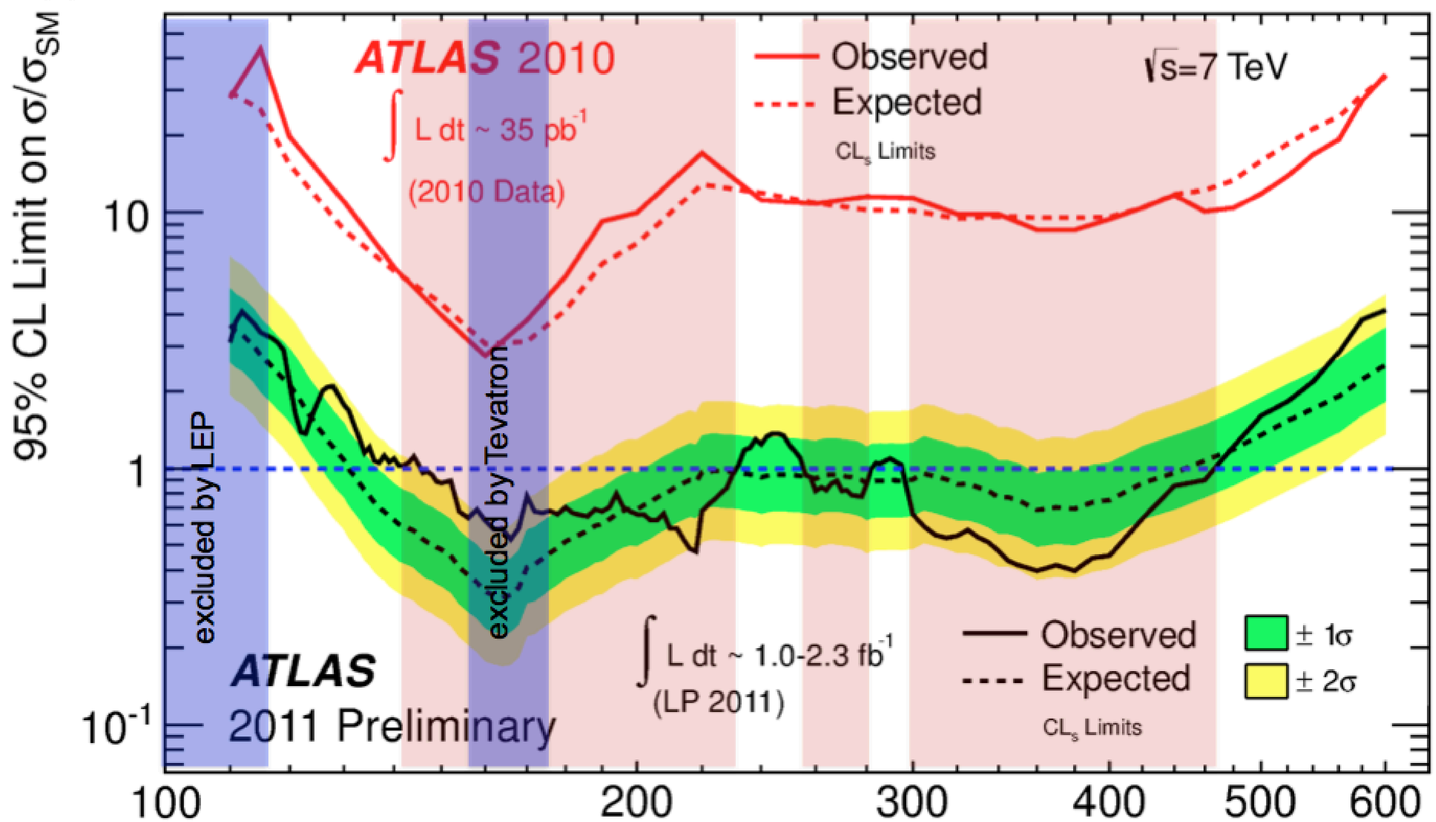
Current Projections



Latest from HCP 2011, Paris

F. Tarrade, ATLAS

SM Higgs Combination at ATLAS with 2010 and 2011 data :

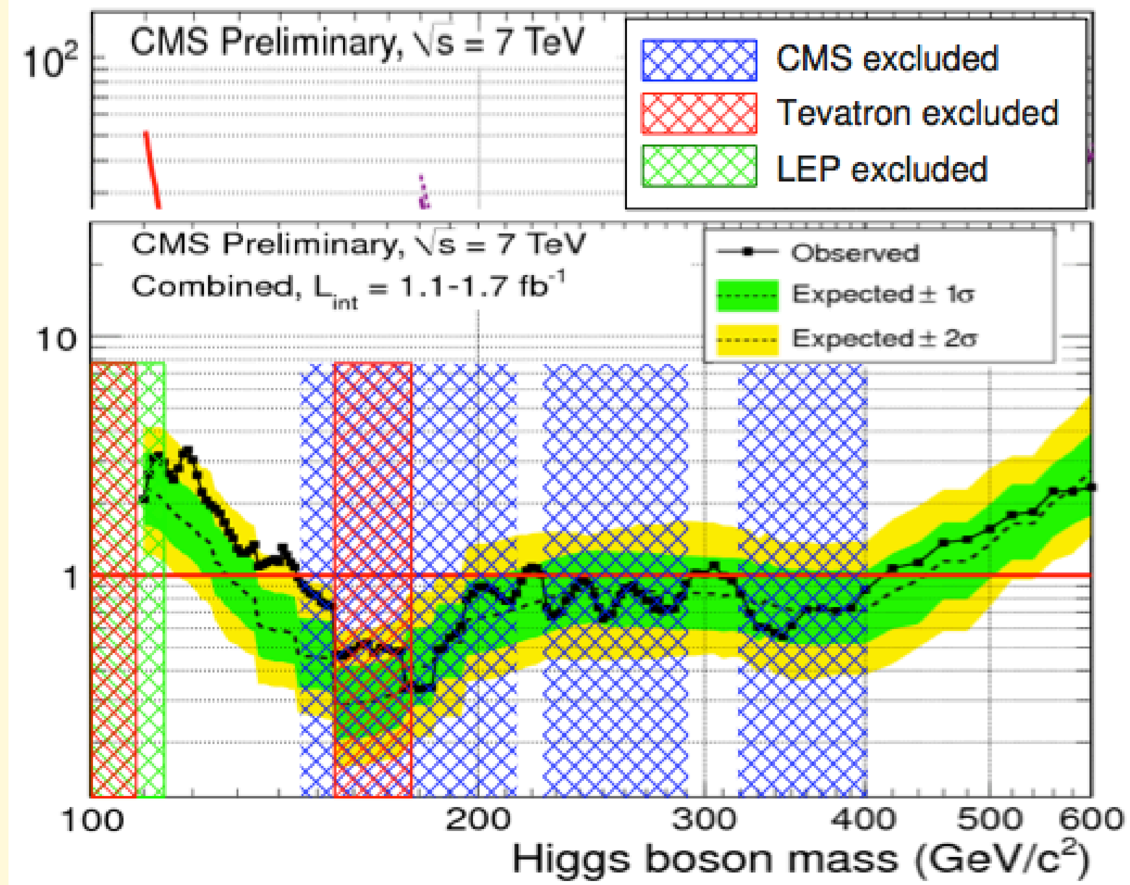


- Expected limit exclusion : ······ 131 - 450 GeV
- Observed limit exclusion : —— 146 - 230 GeV and 256 - 282 GeV and 296 - 459 GeV

M. Bluj, CMS

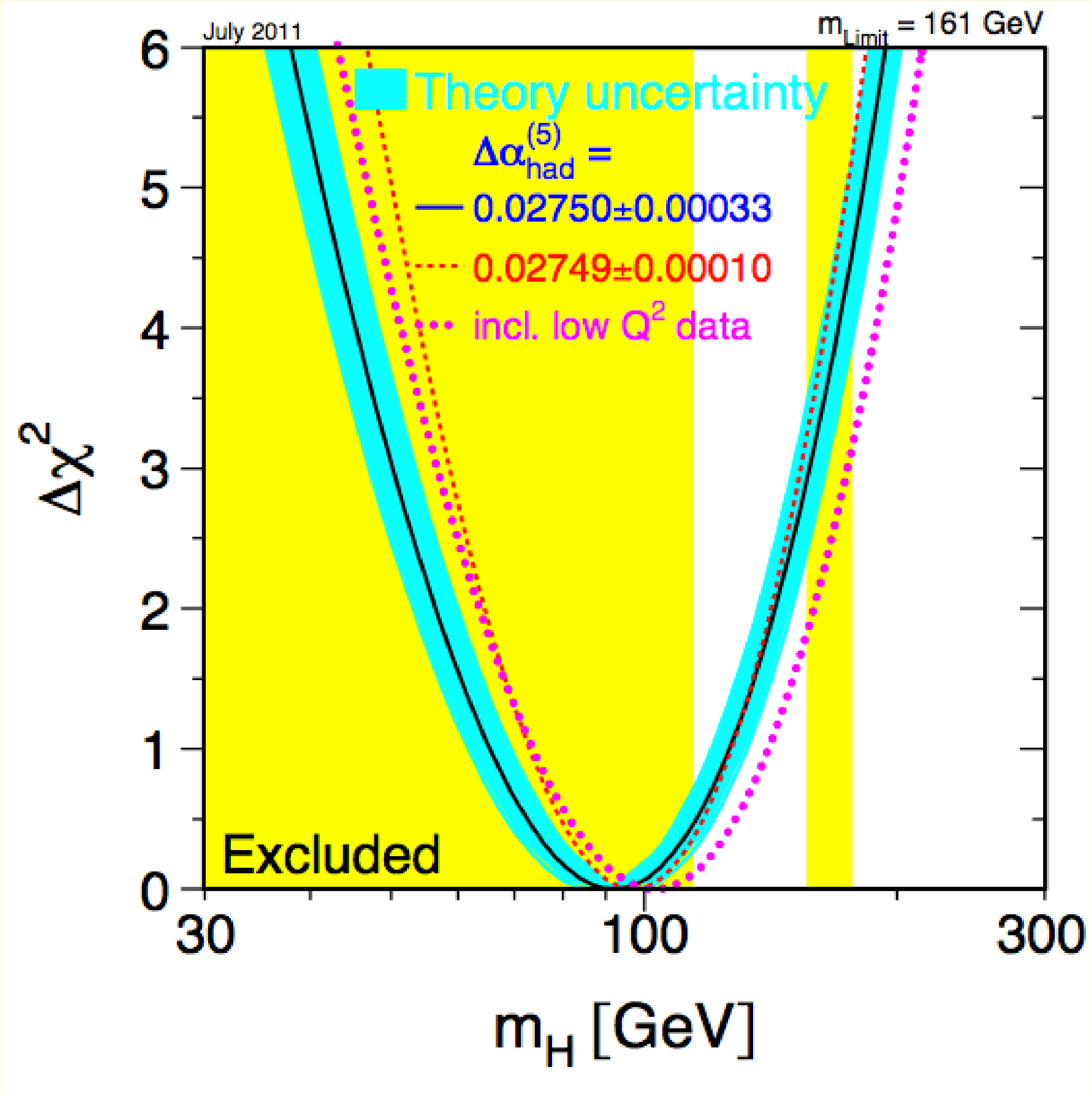
Combined limit (L = 1.1 – 1.7 fb^{-1})

- Solid – observed; dashed – expected



Excluded mass ranges: 145-216, 226-288, 310-400

Performance expectations by and large confirmed



$$M_H = 92^{+34}_{-26} \text{ GeV}$$

$$M_H < 161 \text{ GeV, } 95\% \text{ C.L.}$$

⇒ The most interesting region in m_H is yet to be probed by the LHC experiments

Conclusions that the Higgs may not be there since it's not been seen as yet at the LHC are premature and unjustified!

From an old slide of mine:

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

- 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→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, and/or LC

while it is premature to advocate that we are in such scenarios, it remains true that not seeing the SM Higgs will call for a longer, and higher-luminosity, exploration

So the original motivations for the lum upgrade, drawn from the study of the Higgs and of EWSB, remain valid and compelling

- Establish nature of Higgs boson and of EWSB:
  - fundamental or composite?
  - how many doublets? singlets? charged H's?
- Need to measure, **as accurately as possible*:**
  - Higgs couplings to fermions, gauge bosons and selfcouplings
  - Rare decay modes, possible FCNC
  - WW scattering at high E
  - Gauge boson selfcouplings

* There is no information today to meaningfully determine the scale of the ultimate required accuracy

Example (if H light): Rare Higgs decay modes

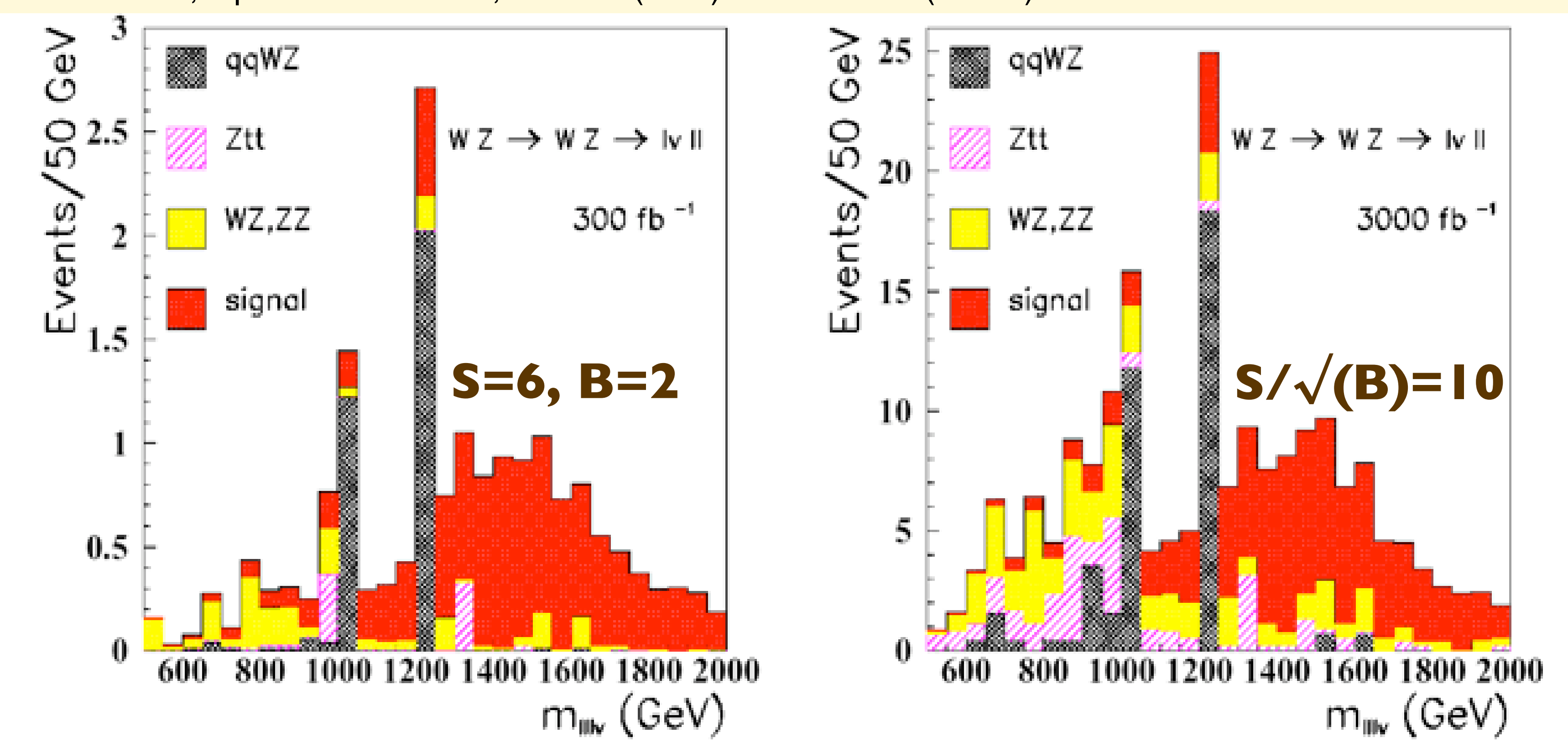
Han, McElrath, hep-ph/0201023

		$600\ fb^{-1}$	$6000\ fb^{-1}$
m[H] ~ [110-140] GeV	$H \to Z\gamma$	$3.5\ \sigma$	$11\ \sigma$
	$H \to \mu^+\mu^-$	$< 3.5\ \sigma$	$\sim 7\ \sigma$

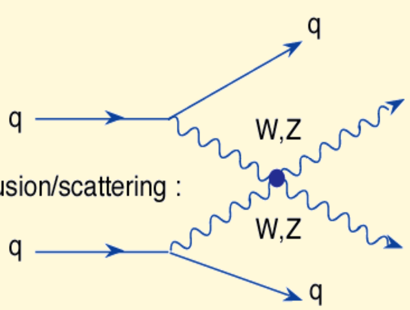
These measurements of rare decay mods are relevant even if H appears to be SM-like, thus high-lum is needed regardless

Example (if H heavy):
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)



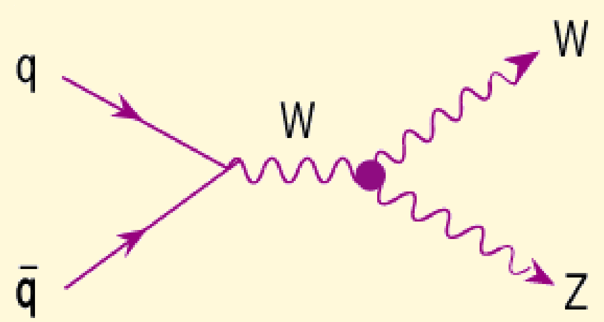
W, Z fusion/scattering :

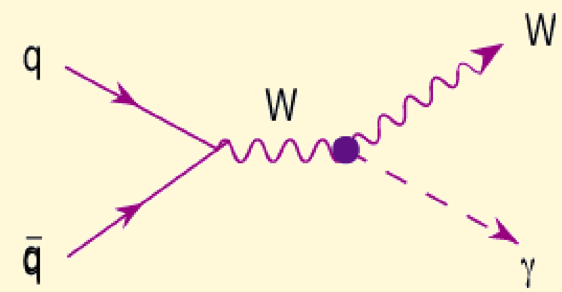


Further explorations of Electroweak Symmetry Breaking:

Precise determinations of the self-couplings of EW gauge bosons

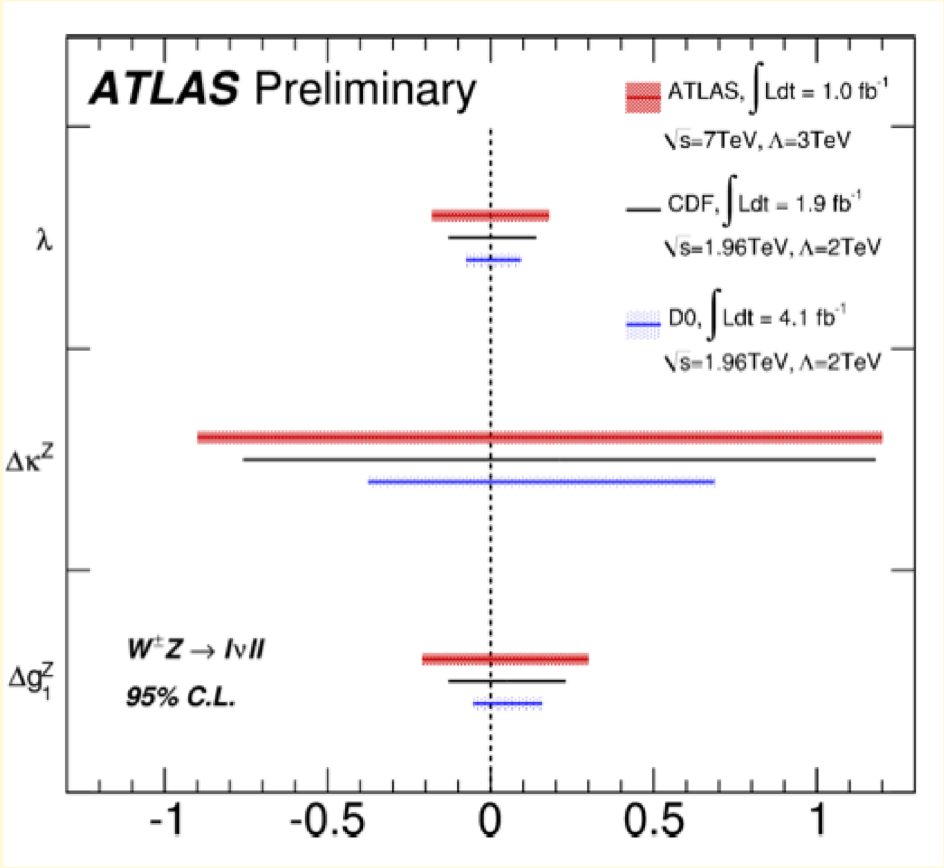
5 parameters describing weak and EM dipole and quadrupole moments of gauge bosons. The SM predicts their value with accuracies at the level of $\mathbf{10^{-3}}$, which is therefore the goal of the required experimental precision

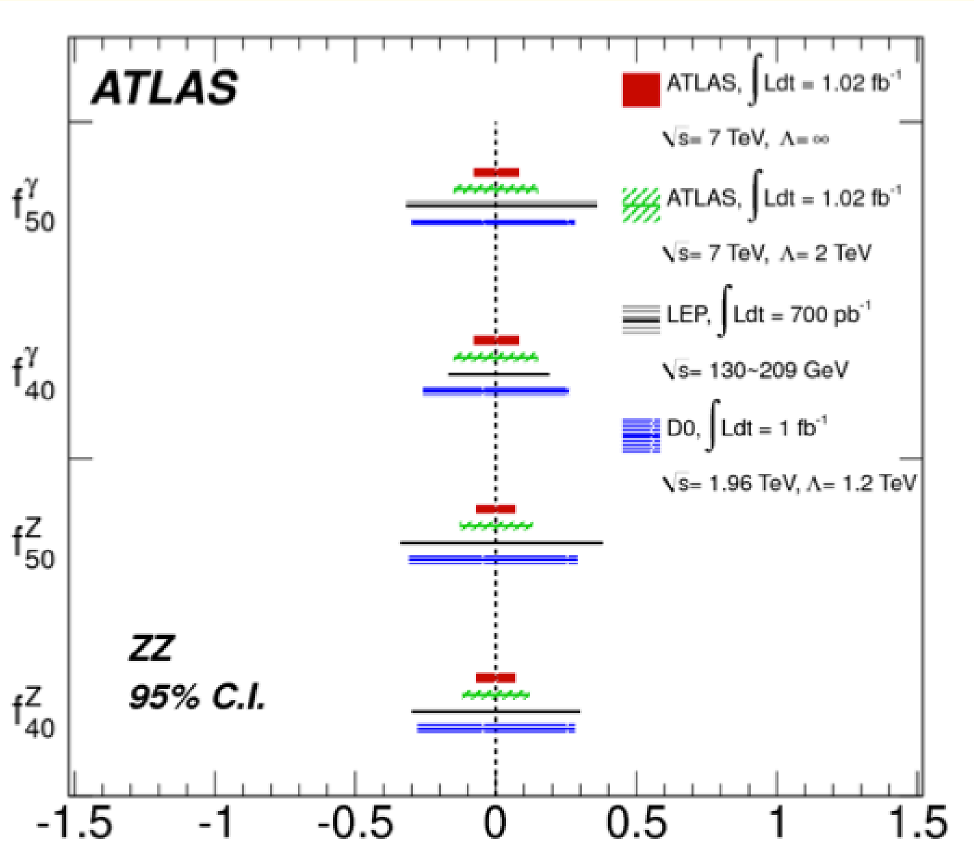




Coupling	14 TeV 100 fb^{-1}	14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	28 TeV 1000 fb^{-1}	LC 500 fb^{-1}, 500 GeV
λ_γ	0.0014	0.0006	0.0008	0.0002	0.0014
λ_Z	0.0028	0.0018	0.0023	0.009	0.0013
$\Delta\kappa_\gamma$	0.034	0.020	0.027	0.013	0.0010
$\Delta\kappa_Z$	0.040	0.034	0.036	0.013	0.0016
$g^Z{}_1$	0.0038	0.0024	0.0023	0.0007	0.0050

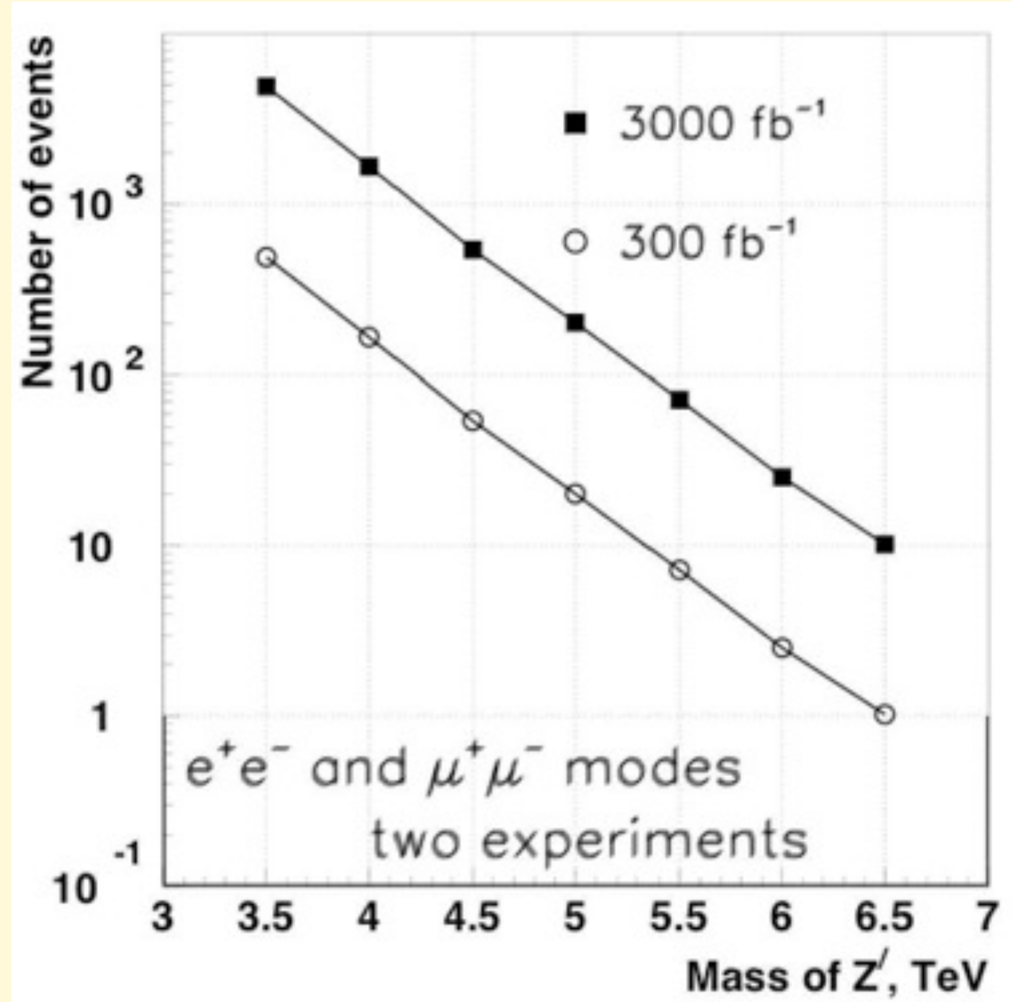
Where we stand today:





Searching new forces: W', Z'

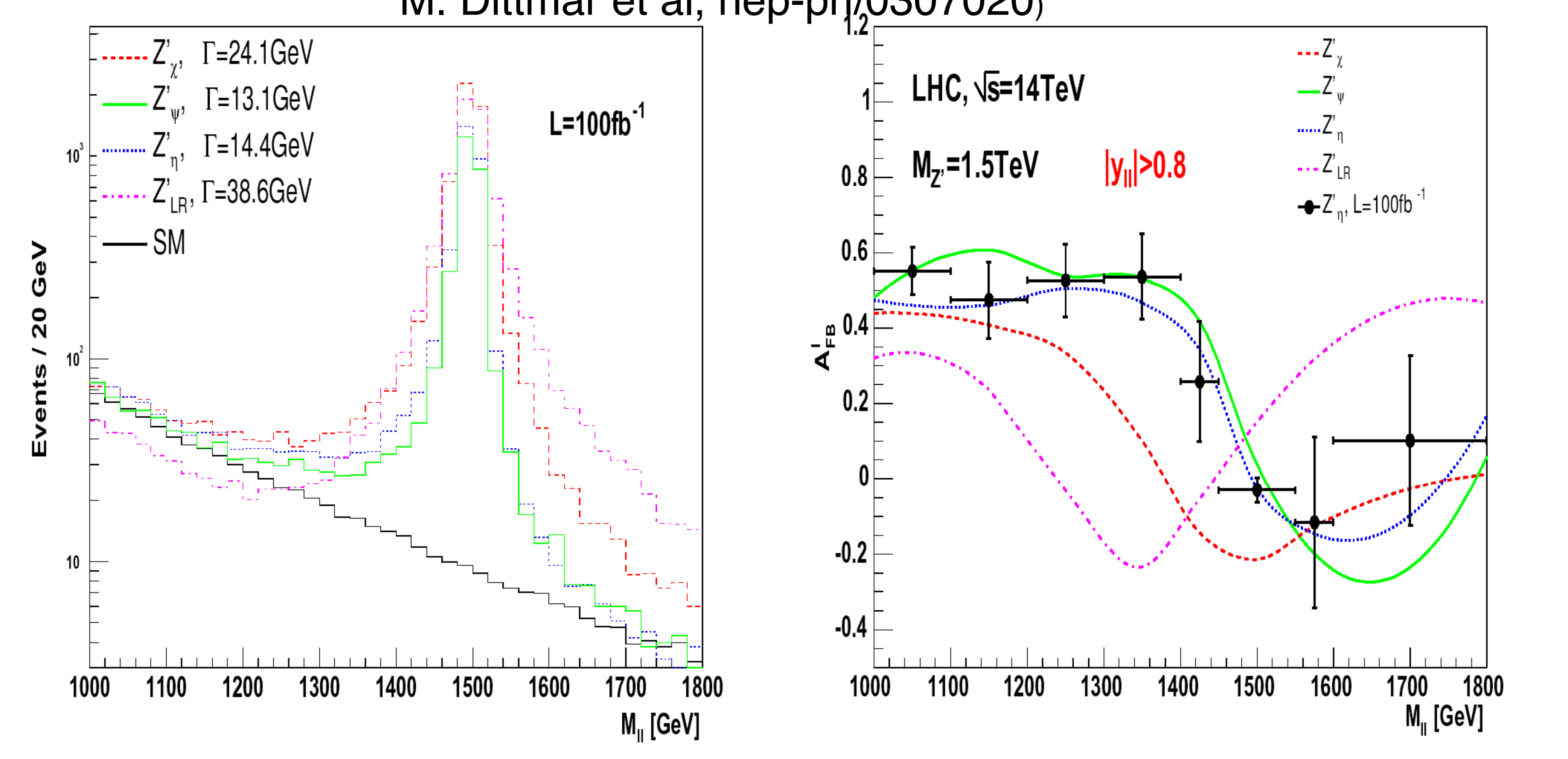
E.g. a W' coupling to R-handed fermions, to reestablish at high energy the R/L symmetry



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

Differentiating among different Z' models:

M. Dittmar et al, hep-ph/0307020)

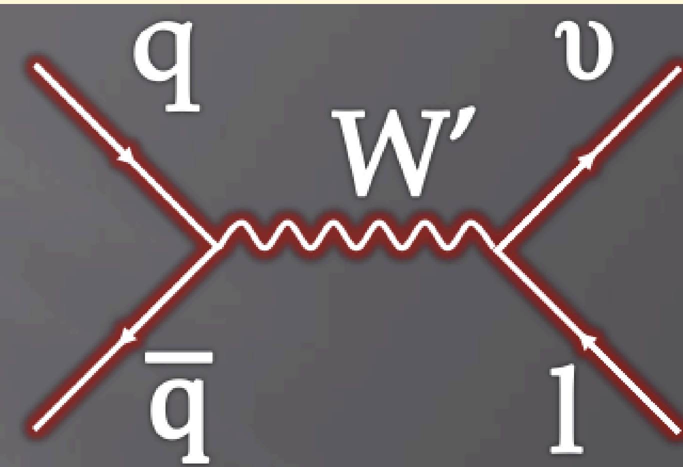


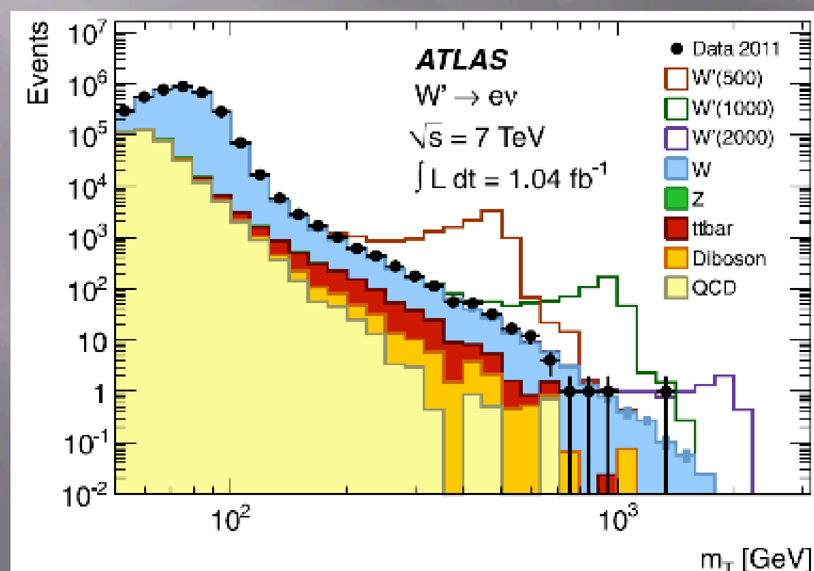
100 fb^{-1} model discrimination up to 2.5 TeV

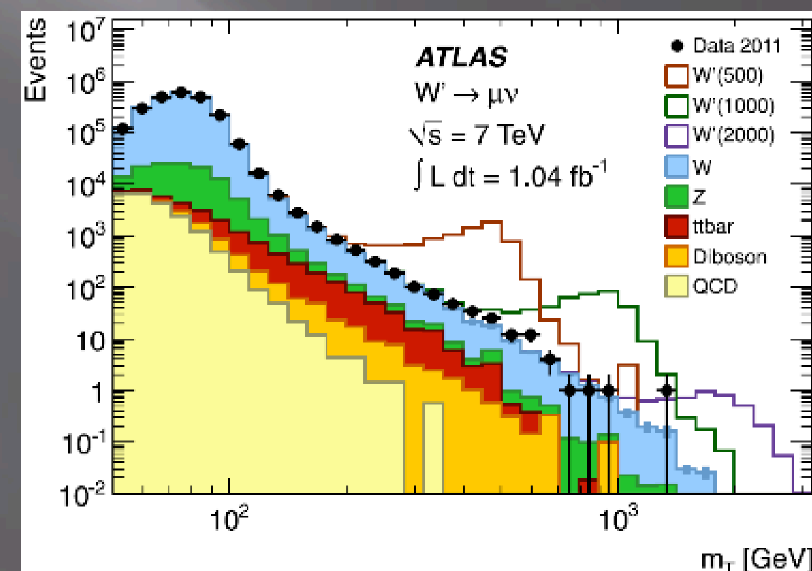
Searches for high-mass resonances, leptonic decays

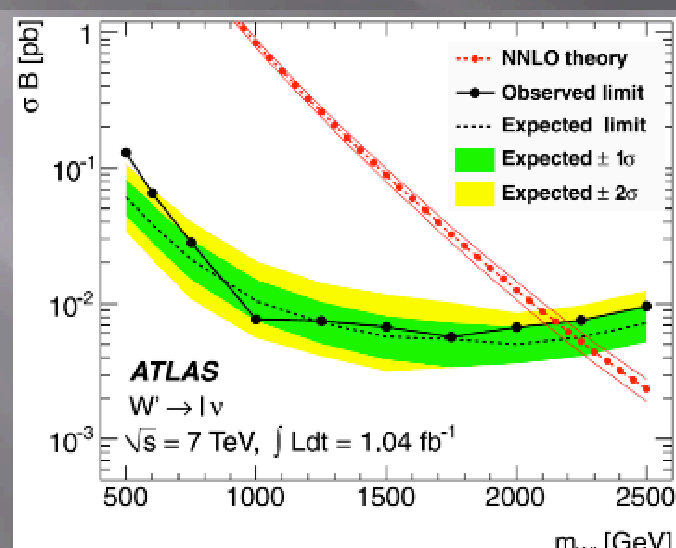
- Benchmark :
  Sequential Standard Model W'
- Observable:

$$m_T = \sqrt{2 p_T E_T^{miss} (1 - \cos(\varphi_{l\,\upsilon}))}$$



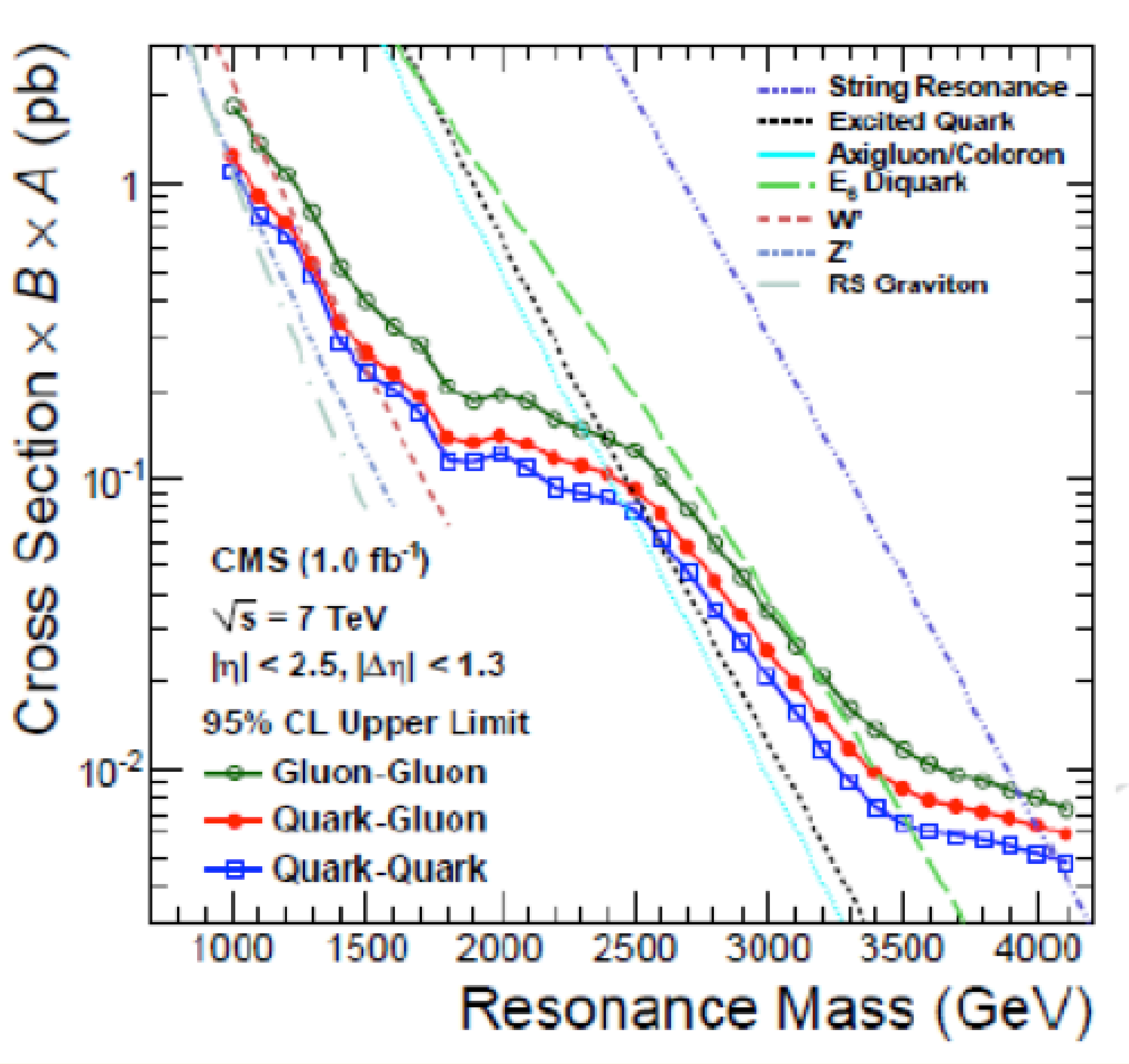






- $m_{W',SSM}$> 2.15 (2.23 exp) TeV
- Electron channel only:
  $m_{W',SSM}$> 2.08 (2.17 exp) TeV
- Muon channel only:
  $m_{W',SSM}$> 1.98 (2.08 exp) TeV

Searches for high-mass resonances, hadronic decays



Mass limits depend greatly on the details of the BSM model being considered, and vary between 1 and 4 TeV

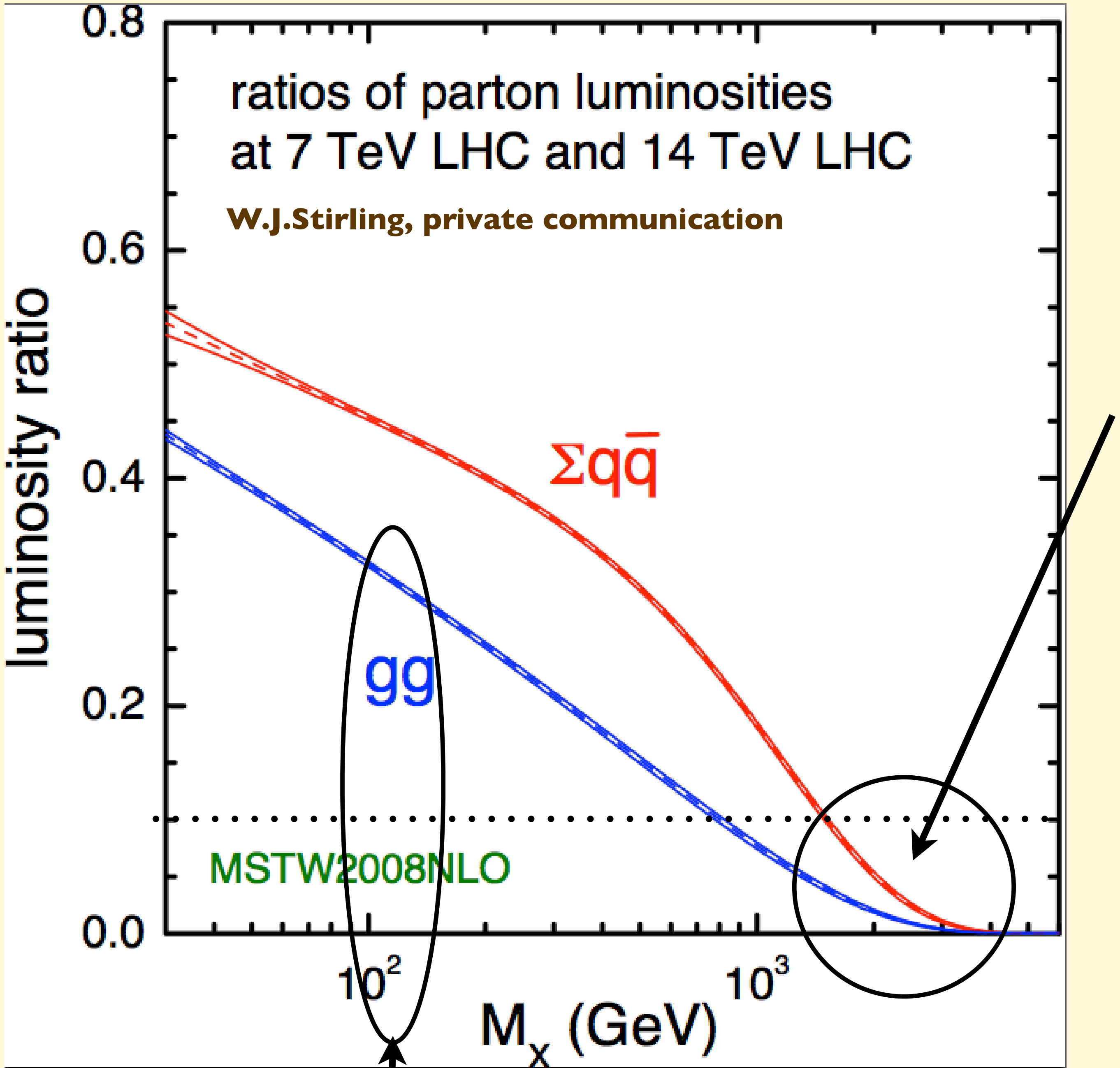
$$\sigma(M,g) \propto \frac{g^2}{M^2}\, L(x = M/\sqrt{S})$$

Production rates can be small either because the mass of the produced object is large, or because the coupling strength is small

To probe higher masses, higher beam energy is clearly preferable

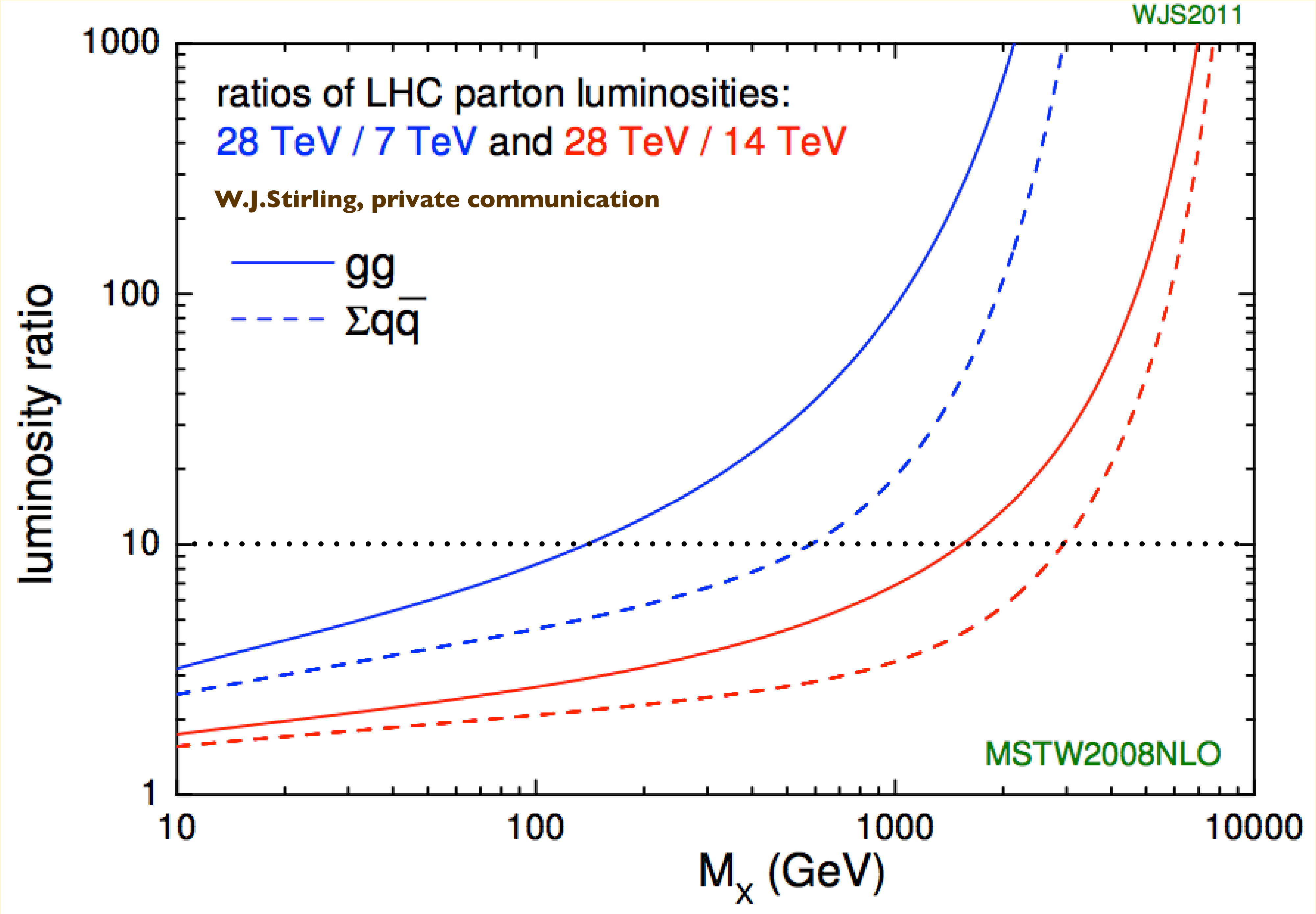
To probe smaller couplings at smaller masses, higher luminosity is what you need

Luminosity vs energy



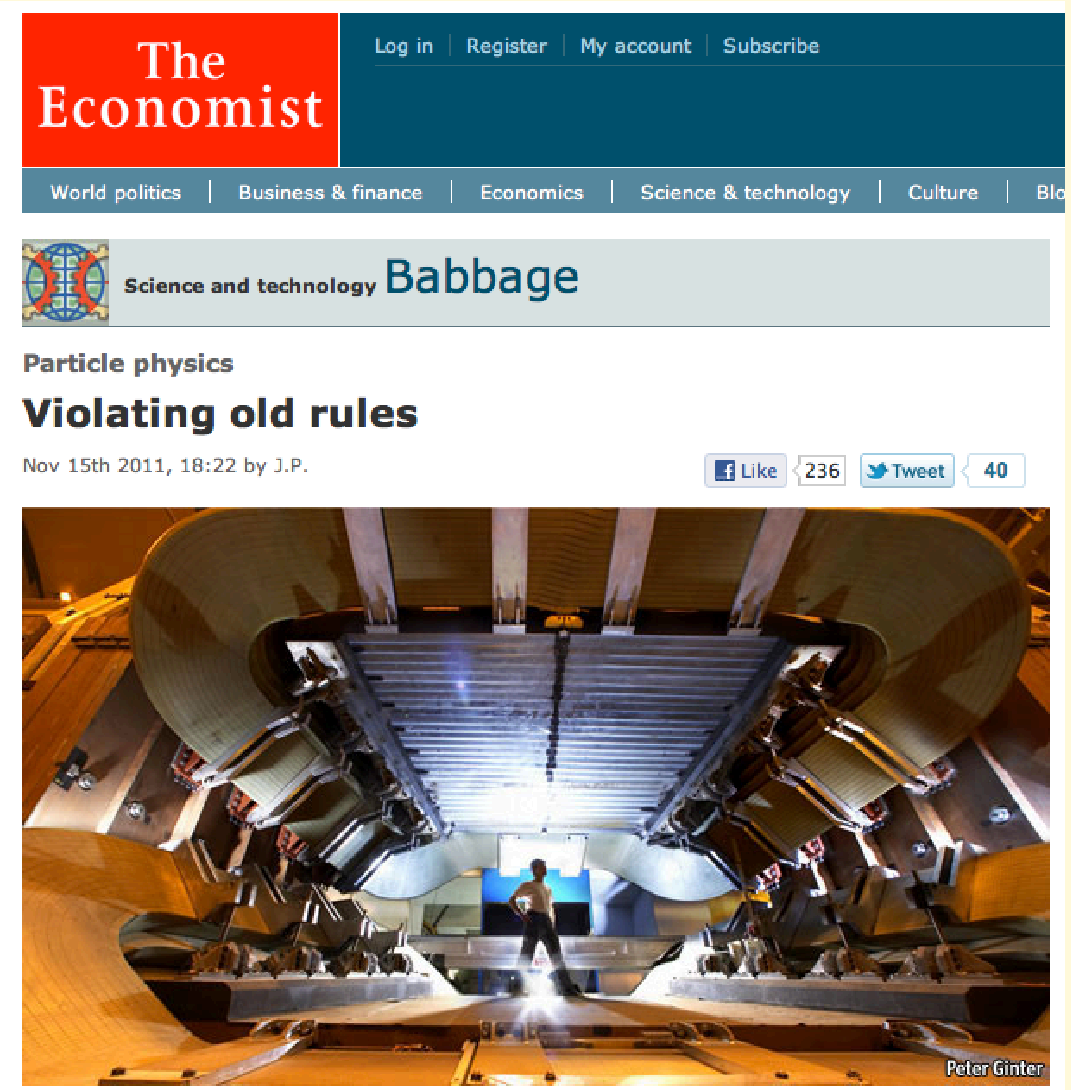
Current highest limits on heavy new particles are already in a region where 7→14 TeV will gain much more than a factor of 10x increase of luminosity

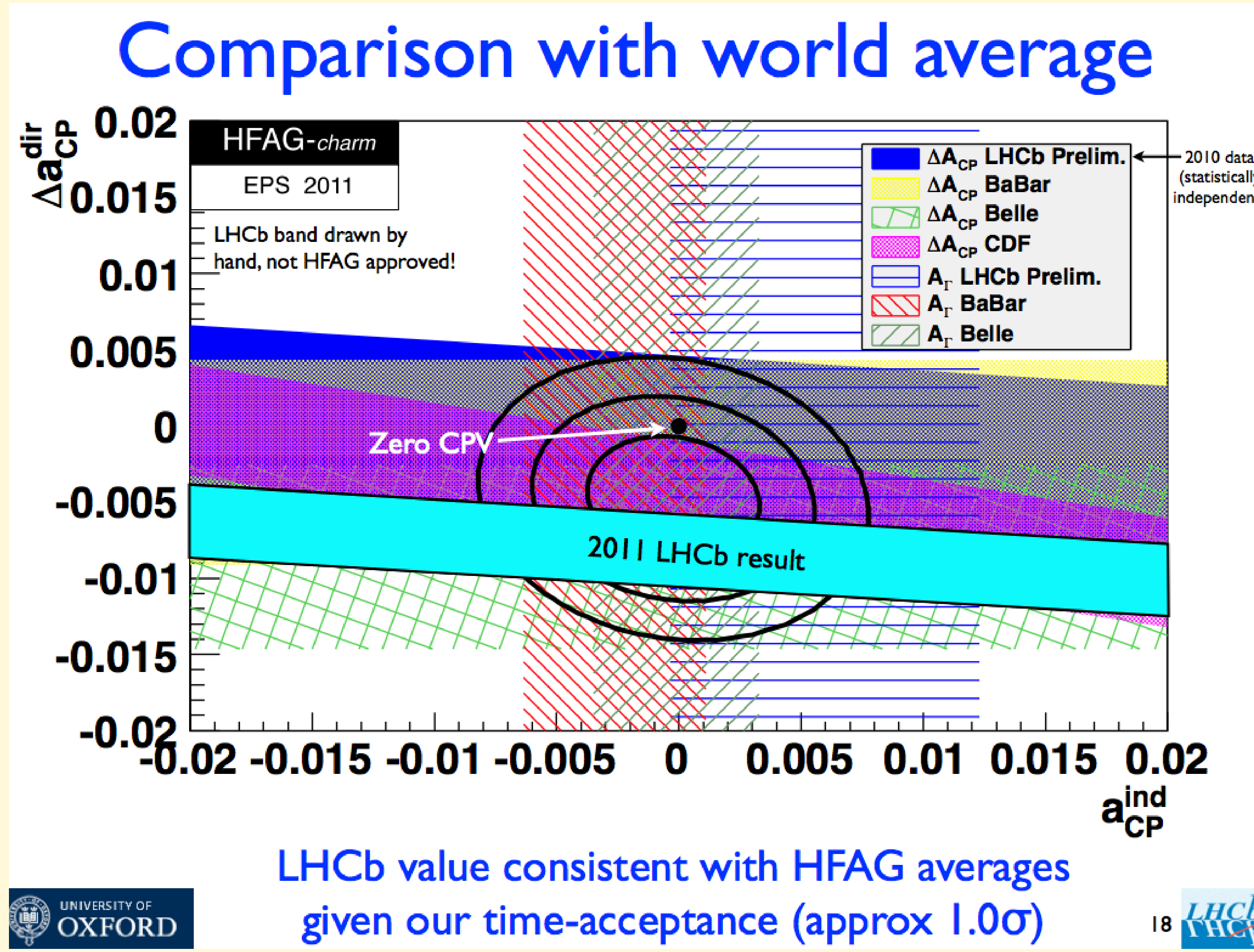
In the case of Higgs searches at low mass, 7→14 TeV is "only" a factor of ~3 in rate



It is still nevertheless too early to enter the territory where the need to move to 28 TeV becomes obvious ....

Observation of direct CP violation in D decays, 3.5σ





$$\Delta A_{CP} = [-0.82 \pm 0.21(\mathrm{stat.}) \pm 0.11(\mathrm{sys.})]\,\%$$

Flavour physics will reveal important information on new physics, and a suitable programme must be kept alive during the high lum phase.

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  - *Will need to explore lower production rates, rarer processes, or worse S/B conditions*
  - *Thus it also strengthens the need for clean experimental conditions (i.e. low pileup)*
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  - *Will need to explore lower production rates, rarer processes, or worse S/B conditions*
  - *Thus it also strengthens the need for clean experimental conditions (i.e. low pileup)*
  - *No new elements to add to the issue of forward jet tagging and expt-LHC interface in the fwd region*
- No evidence of new resonances (W', Z', SUSY, etc).
  - *This implies that, should they exist at all, rates are small, and **high lum** will be needed for the thorough exploration of their properties*