Precision measurements at HL-LHC

Aleandro Nisati, INFN – Rome

outline

- Priorities after the ~125 GeV Higgs boson discovery at CERN
- The LHC Upgrade Plan
- Higgs couplings measurement perspectives
- Higgs Spin/CP
- Vector Boson Scattering, Boson TGCs, Top FCNC
- Conclusion

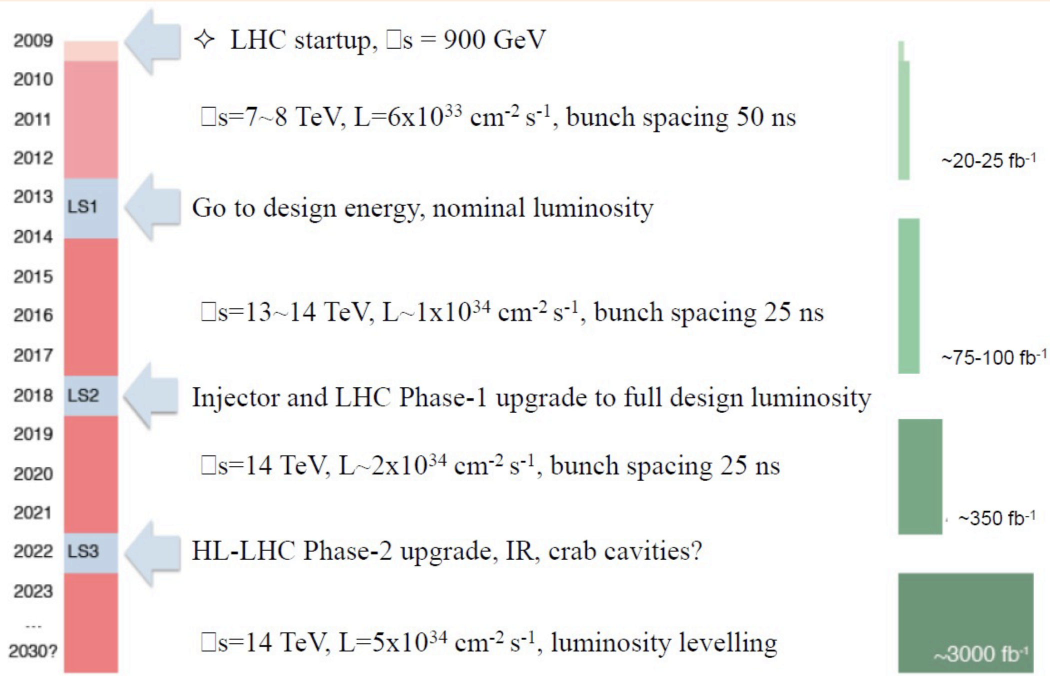
The priorities for energy frontier physics after July 4th

- The recently discovered new particle drives to a number of fundamental open points that are top priority for the physics programme for the LHC and future energy frontier accelerators:
  1. Precision measurement of the mass and of the natural width of this new particle
  2. Determination of the quantum numbers spin and parity, J^P, and CP properties
  3. Measurement of couplings to elementary fermions and bosons
  4. Measurement of the self-coupling strength
  5. Comparison of these physics properties with those predicted by Standard Model
  6. Search for possible partners (neutral/charged) of this boson
  7. Is this particle a fundamental object, or it is composite?

The priorities for energy frontier physics after July 4th

8. Analyse the Vector Boson scattering cross section to study whether the cross-section regularization is operated by the Higgs boson (as predicted by SM) or (also) by other processes associated to physics beyond SM;
9. Continue the search for SUSY particles, in particular search for third generation squarks: to be effective, the mass of the stop quark cannot be too different from the on of the top quark; also continue the search for gauginos and for 1st and 2nd generation squarks;
10. Continue the search for heavy resonances decaying to photon, lepton or quark pairs, and for deviations from SM of physics distributions highly sensitive to New Physcs (di-jet angular distribution,…)

The LHC Upgrade plan



About 350 fb^{-1} are expected at the end of the LHC Programme

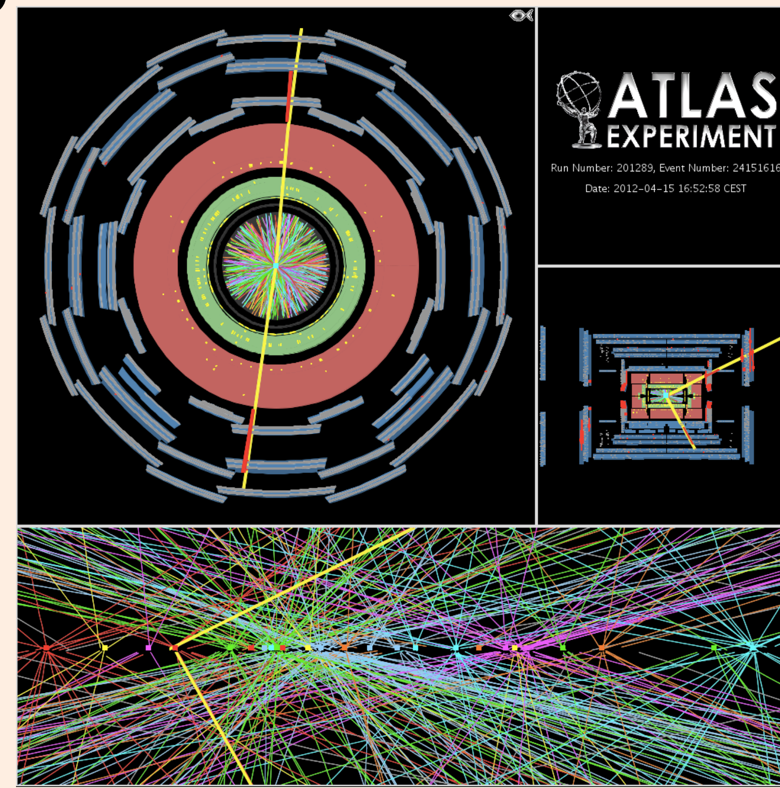
- 300 fb^{-1} have been assumed as baseline in the studies made by ATLAS and CMS

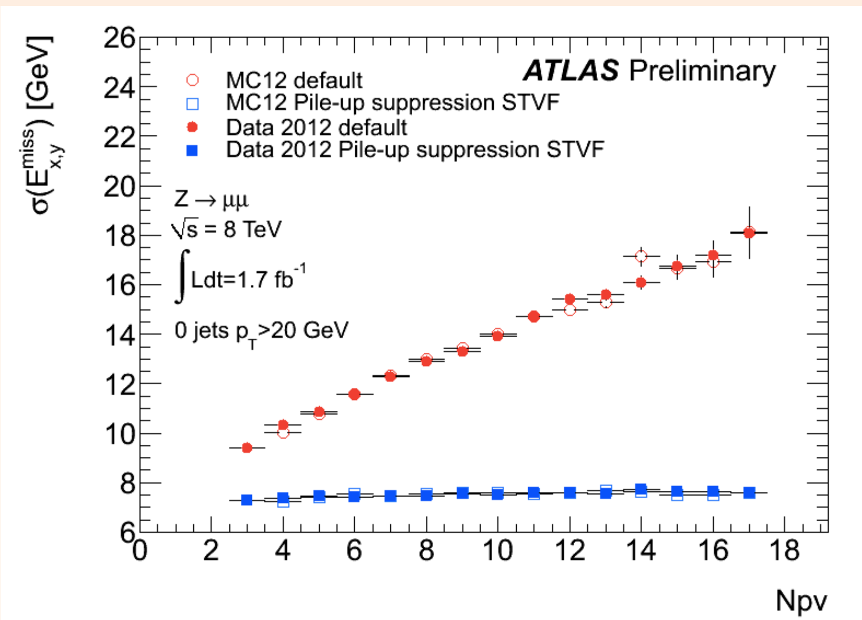
- Experimental challenges
  - The average number of proton-proton collisions per triggered events is about 140
  - The trigger has to cope with the effects induced by the large pile-up
  - The inner detector has to be fast and with high granularity and redundancy, to cope with the effects from large occupancy
  - The detector has to be (even more) radiation hard

Event pileup at the LHC

- Present ATLAS and CMS detectors have been designed for <μ> ~ 23 pp interactions / bunch-crossing
  - And continue to do an excellent job with 35

Z→μμ decay in a large pileup event





Missing transverse energy resolution as a function of the number of the reconstructed vertices

- But cannot handle (an average of) 140 events of pileup

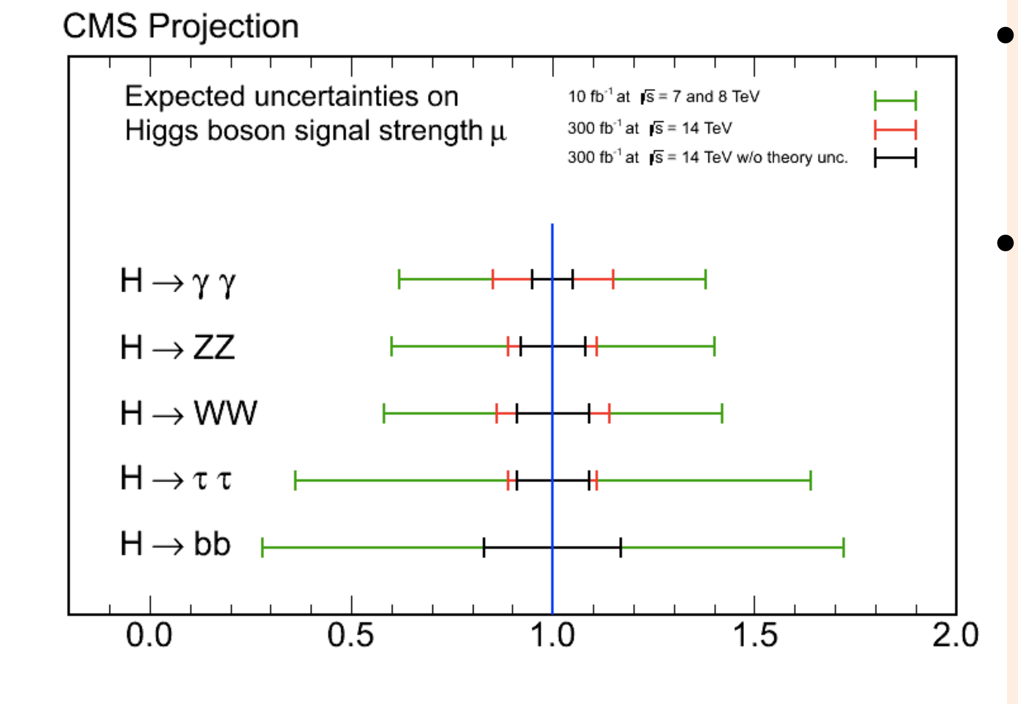
Approaches adopted for physics perspectives estimation

- **ATLAS**: perform physics simulation with a fast procedure based on simple functions applied to physics objects (electrons, photons, muons, tau, jets, b-jets, missing transverse energy) to mimic the effects from energy (momentum) resolution; acceptance, identification and reconstruction efficiencies, b-tagging efficiencies, fake rates
- **CMS**: the upgraded detector will compensate the effects from event pile-up; assume three different scenarios:
  - Scenario 1: all systematic uncertainties are kept unchanged wrt those in current data analyses
  - Scenario 2: the theoretical uncertainties are scaled by a factor of 1/2, while other systematic uncertainties are scaled $\sqrt{L}$;
  - Scenario 3: set theoretical uncertainties to zero, to demonstrate their interplay with the experimental uncertainties;
  - ➔ The truth will be most likely somewhere between Scenario 1 and 2

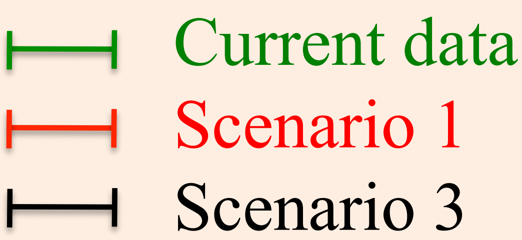
Higgs Couplings at the LHC

- The LHC programme will be completed by about 2021 with an integrated luminosity around 300 fb^{-1}.
- Important progress can be made on the analysis of the physics properties of the Higgs-like boson recently discovered

https://indico.cern.ch/contributionDisplay.py?contribId=177&confId=175067



- Estimated precision of the signal strength determination for a SM Higgs boson
- Projections for L=300 fb^{-1} and $\sqrt{s}$ = 14 TeV



Signal strengths consistency with SM predictions can be tested with 10-15% accuracy

Higgs Couplings at the HL-LHC

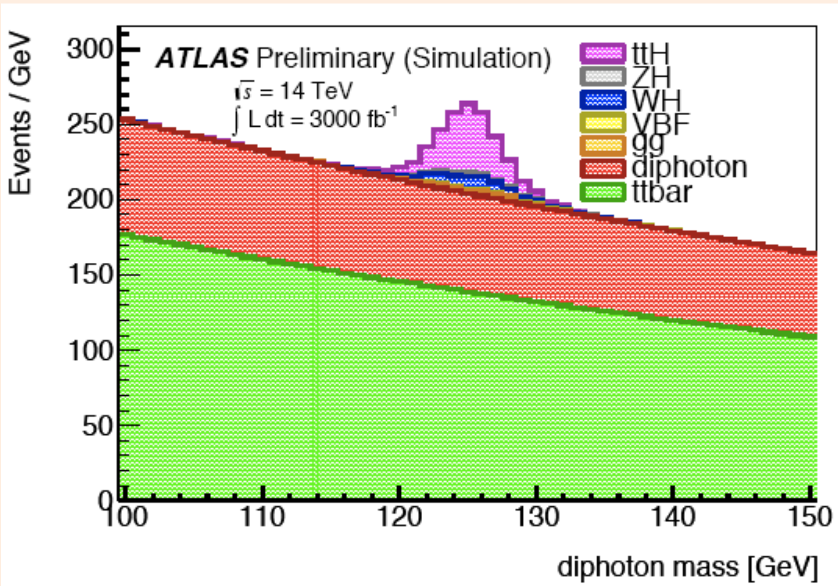
- ATLAS has performed projection studies to HL-LHC, assuming up to 3000 fb^{-1} of data
- focused on the main channels already under study with LHC data, plus a few rare decay channels sensitive to top and muon couplings

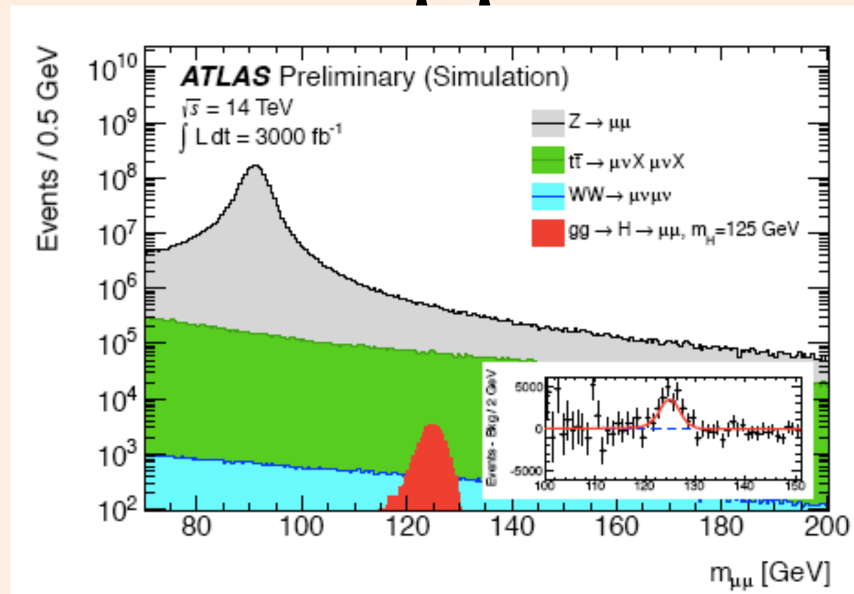
ATL-PHYS-PUB-2012-004

	ggF	VBF H	WH	ZH	ttH
$H \rightarrow \gamma\gamma$	✔	✔	✔	✔	✔
$H \rightarrow ZZ^*$	✔				
$H \rightarrow WW^*$	✔	✔	✔		
$H \rightarrow \tau\tau$	extrap.	✔			
$H \rightarrow \mu\mu$	✔				✔

- ZH,H→bb was studied, but S/B is bad and it it very difficult at present to estimate systematic uncertainties at $L=5x10^{34}$ cm^{-2} s^{-1} ➔ not included in the available ES ATLAS studies

ttH, H→γγ and H→μμ

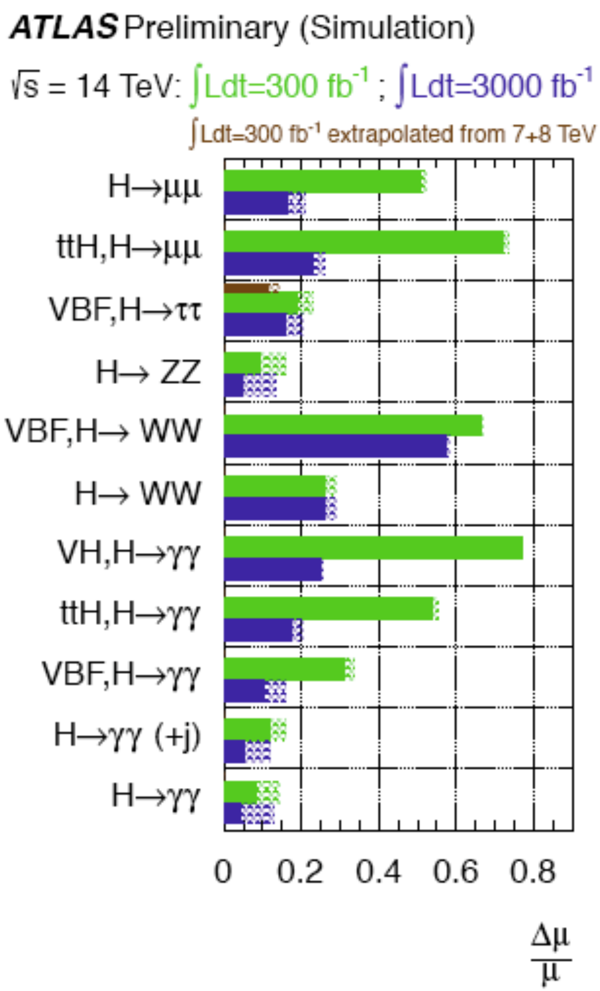


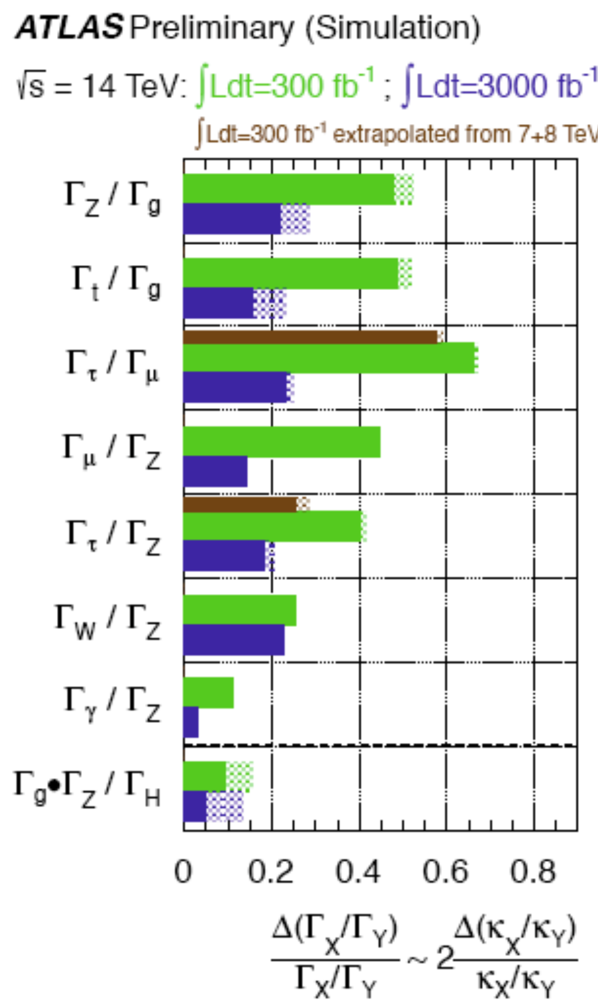


- Important for H-top coupling measurement
- Require multi-jet high-p_T jets
- Analyse 1-lepton and 2- lepton events
- Require very high luminosity
  - $S/\sqrt{B} \sim 6$
  - A factor 2 better than 300 fb^{-1}

- One of the best channels to study Higgs boson couplings to fermions
- Very rare: deviations from the expected rate would indicate new physics
  - Large background from Z→μμ
- Analysis included background modeling uncertainties
- More than 6 sigma at L=3000 fb^{-1}

Higgs Couplings at the HL-LHC





Left: Expected measurement precision on the signal strength $\mu = (\sigma\times BR)/(\sigma\times BR)_{SM}$ in all considered channels.

Right: Expected measurement precisions on ratios of Higgs boson partial widths without theory assumptions on the particle content in Higgs loops or the total width.

	$300\ fb^{-1}$	$3000\ fb^{-1}$
κ_V	3.0% (5.6%)	1.9% (4.5%)
κ_F	8.9% (10%)	3.6% (5.9%)

Expected precision for the determination of the coupling scale factors k_V and k_F. No additional BSM contributions are allowed in either loops or in the total width (numbers in brackets include current theory systematic uncertainties).

Higgs Couplings at the HL-LHC

CMS Coupling	Uncertainty (%)			
	300 fb^{-1}		3000 fb^{-1}	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
κ_γ	6.5	5.1	5.4	1.5
κ_V	5.7	2.7	4.5	1.0
κ_g	11	5.7	7.5	2.7
κ_b	15	6.9	11	2.7
κ_t	14	8.7	8.0	3.9
κ_τ	8.5	5.1	5.4	2.0

- Coupling CMS projection: In the first one (Scenario 1) all systematic uncertainties are kept unchanged. In the second one (Scenario 2) the theoretical uncertainties are scaled by a factor of 1/2, while other systematical uncertainties are scaled by the square root of the integrated luminosity.

Couplings can be measured at the level of few %

Higgs boson Self-Coupling

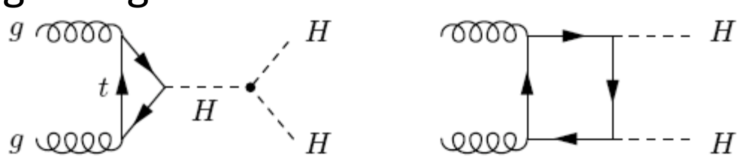
- The only way to reconstruct the scalar potential of the Higgs doublet field , that is responsible for spontaneous electroweak symmetry breaking, it is necessary to measure the Higgs boson self–interactions

$$\lambda_{HHH} = \frac{3M_H^2}{v}$$

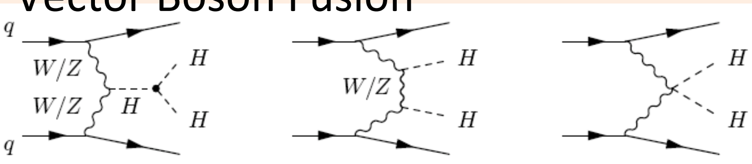
$$V_H = \mu^2 \Phi^\dagger \Phi + \frac{1}{2}\lambda(\Phi^\dagger\Phi)^2 \; ; \quad \lambda = \frac{M_H^2}{v^2} \text{ and } \mu^2 = -\frac{1}{2}M_H^2$$

A. Djouadi, et al., Eur. Phys. J. C10 (1999), 45

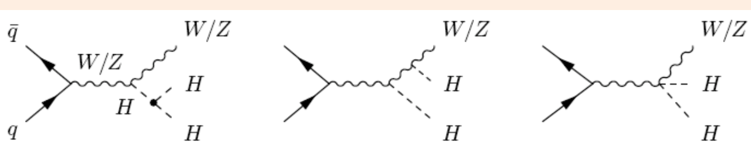
gluon-gluon fusion

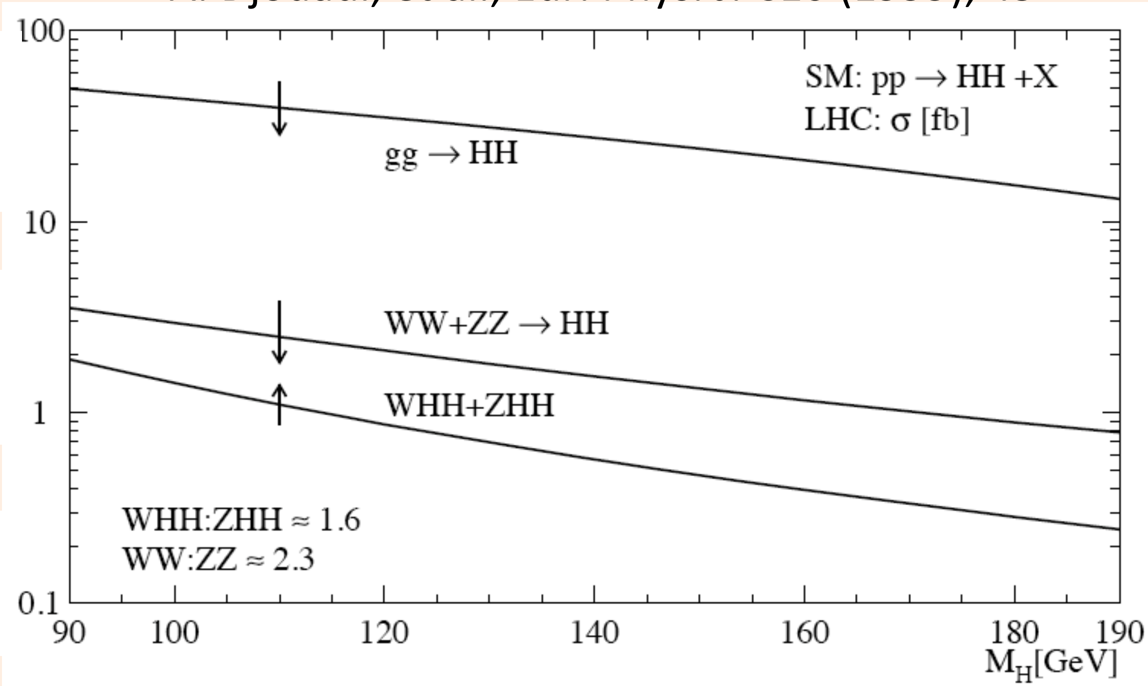


Vector Boson Fusion



Higgs-strahlung





σ_{HH} (14 TeV) = 33.89 +18%-15% (QCD) ±7% (PDF+α_S) ±10% (EFT) fb → +37.2 -29.8 fb

A. Djouadi, et al., http://arxiv.org/abs/1212.5581

Higgs Self-Coupling

ATL-PHYS-PUB-2012-004
ATL-PHYS-PUB-2013-001

Decay channel	Branching ratio (%)	Events @ 14 TeV (L = 3,000 fb^{-1})
b**b** + b**b**	33.4084	33,976
b**b** + W^+W^-	24.9696	25,394
b**b** + $\tau^+\tau^-$	7.3638	7,488
W^+W^- + W^+W^-	4.6656	4,745
ZZ + b**b**	3.0866	3,138
ZZ + W^+W^-	1.1534	1,174
$\gamma\gamma$ + b**b**	0.2658	270
$\gamma\gamma$ + $\gamma\gamma$	0.0010	1

Expected SM HH yields for proton-proton collisions at $\sqrt{s}$ = 14 TeV and L=3000 fb^{-1}

- The "trouble" with a 125 GeV Higgs: it decays in many final states with similar "small" B.R. This is very good for couplings, but opens real challenges for HH final states, characterized by small production rates.
- The selection of HH processes has to account for:
  - Final states experimentally clear and robust
  - Final states with large enough production rates

Two channels have been considered by ATLAS for the "European Strategy":

1. **HH→bbWW**
2. **HH→bbγγ**

HH→bbWW

- BR ~ 25% → 2.6 × 10^4 events in 3000 fb^{-1} at 14 TeV;
  - This includes all W decay modes
- The ttbar process represents a severe background for this final state;
- Study done considering one W decaying hadronically, the other leptonically (e,μ; treated separately)
- Select events with high lepton p_T, large missing transverse energy, four high-p_T jets, of which two b-tagged;
- The result of the study shows how challenging is extract HH production from this channel
  - We select <~ 1000 signal events on top of 10^7 ttbar events
  - S/B in agreement with estimates performed by other authors (M.J. Dolan et al., arXiv:1206.5001v2 [hep-ph])

HH → bbγγ

- BR ~ 0.27% , $\sigma \times$ BR ~ 0.09 fb → 260 HH events in 3000 fb^{-1} at 14 TeV;
- bbγγ, Zbb, Hbb, ttbar are important backgrounds
- Select events with high-p_T photons, two jets b-tagged; reconstruct the invariant mass of the b-jets and of the photons and select events with $m_{\gamma\gamma}$ and $m_{bb} = m_Z$ within experimental mass resolution

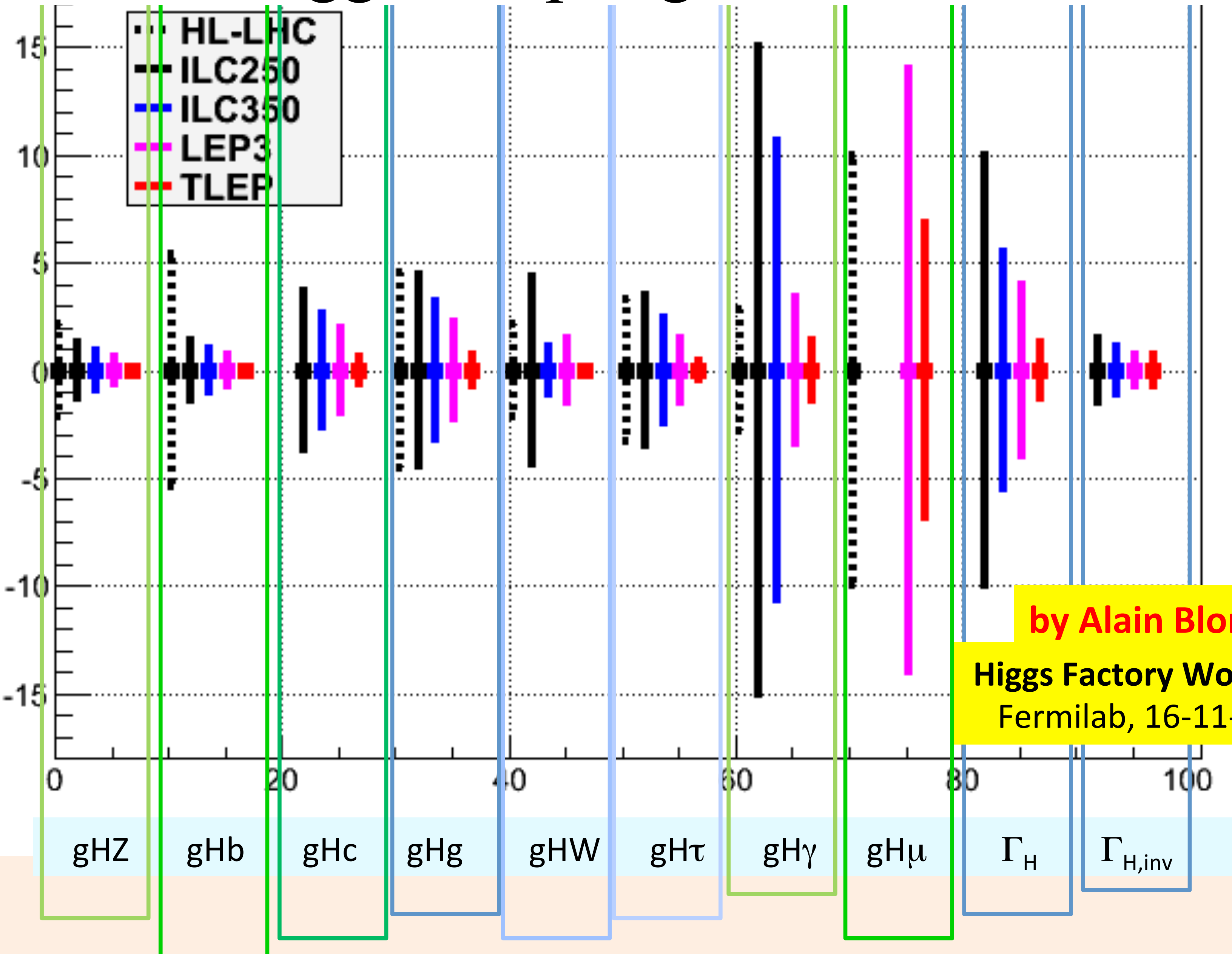
HH → bbγγ

ATLAS Note: ATL-PHYS-PUB-2013-001

sample	$\sigma\times$BR (fb)	simulated events	events passing selection	events expected in 3000 fb^{-1}
$HH \to b\bar{b}\gamma\gamma$ ($\lambda_{HHH} = 1$)	0.09	1020	42	10.7
$HH \to b\bar{b}\gamma\gamma$ ($\lambda_{HHH} = 0$)	0.19	1020	32	17.9
$HH \to b\bar{b}\gamma\gamma$ ($\lambda_{HHH} = 2$)	0.04	1230	66	6.4
$\gamma\gamma b\bar{b}$	111	3.1×10^4	1	1.1
$ZH(Z\to b\bar{b}, H\to\gamma\gamma)$	0.04	5×10^5	11600	2.8
$b\bar{b}H(H\to\gamma\gamma)$	0.124	5×10^4	71	0.5
$\gamma\gamma jj$	2×10^3	5×10^5	0.004	0.1
$jjjj$	1.8×10^8	4.6×10^6	0	0
$t\bar{t}H(H\to\gamma\gamma)$	1.71	1.2×10^5	379	13.6
$t\bar{t}$ ($\geq$ 1 leptonic W decay)	5.0×10^5	1×10^7	$74^\dagger$	1.1
Total Background	-	-	-	19.2

- Select 11 HH events with a total background yield of 19 events
- Assuming that we can add another channel with similar performances (HH→ττbb ?) and two experiments, we can reach a measurement of the Higgs boson selfcoupling with an accuracy of ~30%

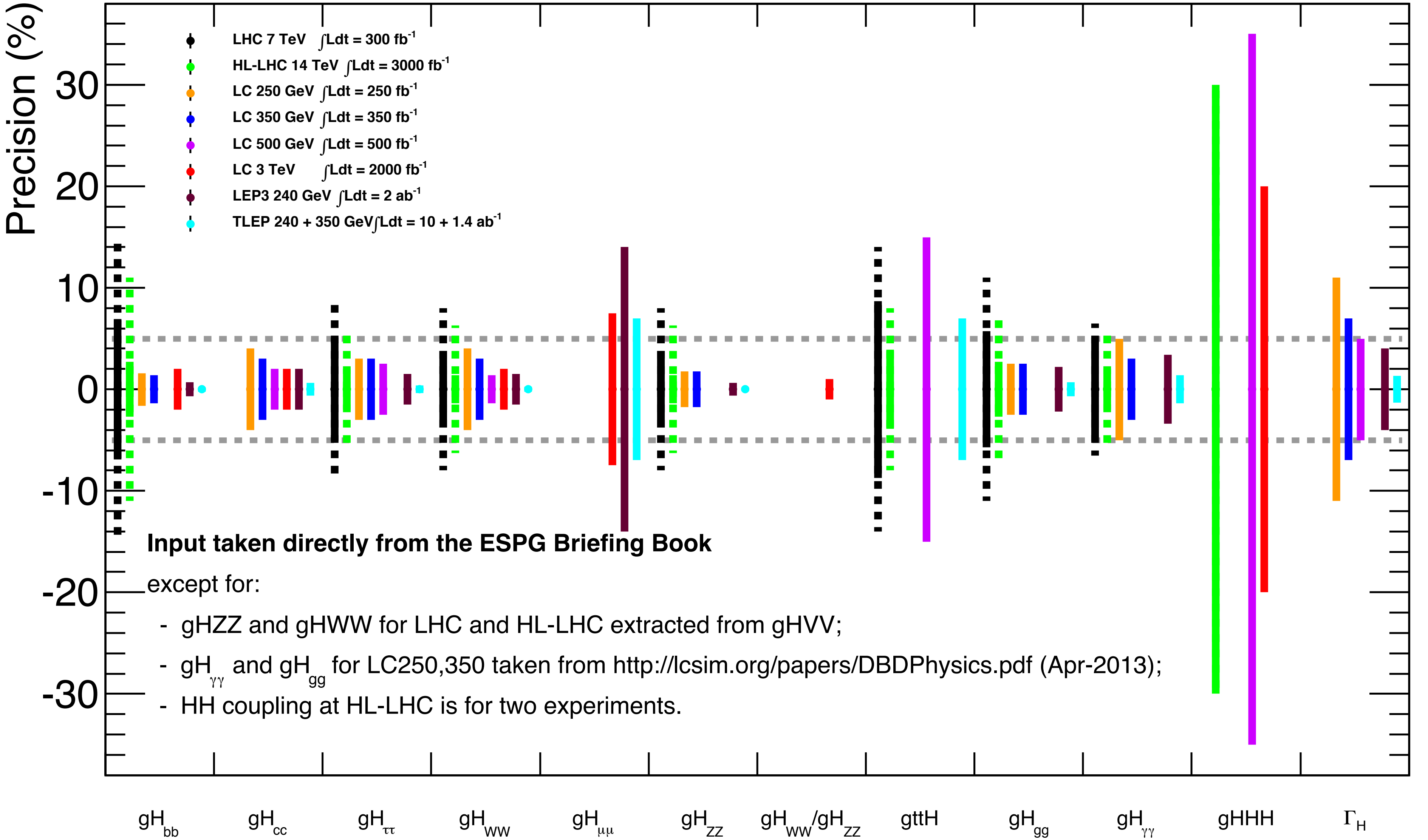
Higgs Couplings Overview



by Alain Blondel

Higgs Factory Workshop
Fermilab, 16-11-2012

Higgs Couplings Overview



Higgs boson CP

- Explore the ATLAS sensitivity to the CP-violating part of the HZZ scattering amplitude:

$$A(X \to VV) \sim \left(a_1 M_X^2 g_{\mu\nu} + a_2 (q_1 + q_2)_\mu (q_1 + q_2)_\nu + a_3 \varepsilon_{\mu\nu\alpha\beta} q_1^\alpha q_2^\beta\right) \varepsilon_1^{*\mu} \varepsilon_2^{*\nu}$$

- ε: polarisation vectors of the gauge bosons, form factors a_1 and a_2 refer to CP-even boson with mass M_X, a3 to a CP-odd boson
  - The presence of the two CP terms can lead to CP violation
  - In SM $a_1=1$; $a_2=a_3=0$
- In this study we have set $a_1=1$; $a_2=0$, and varied a_3

Integrated Luminosity	Signal (S) and Background (B)	$6+6i$ $f_{a3} > 0.63$	$6i$ $f_{a3} > 0.46$	$4+4i$
100 fb^{-1}	$S = 158$; $B = 110$	3.0	2.4	2.2
200 fb^{-1}	$S = 316$; $B = 220$	4.2	3.3	3.1
300 fb^{-1}	$S = 474$; $B = 330$	5.2	4.1	3.8

Expected significances in sigma to reject a CP-violating state in favour of 0+ hypothesis as a function of integrated luminosity for various strength of CP-violating contribution.

Precise measurement of smaller form factors which are more likely to be realized will require higher luminosities only accessible at HL-LHC. A similar conclusion can be drawn for the observation of anomalous form factor a2

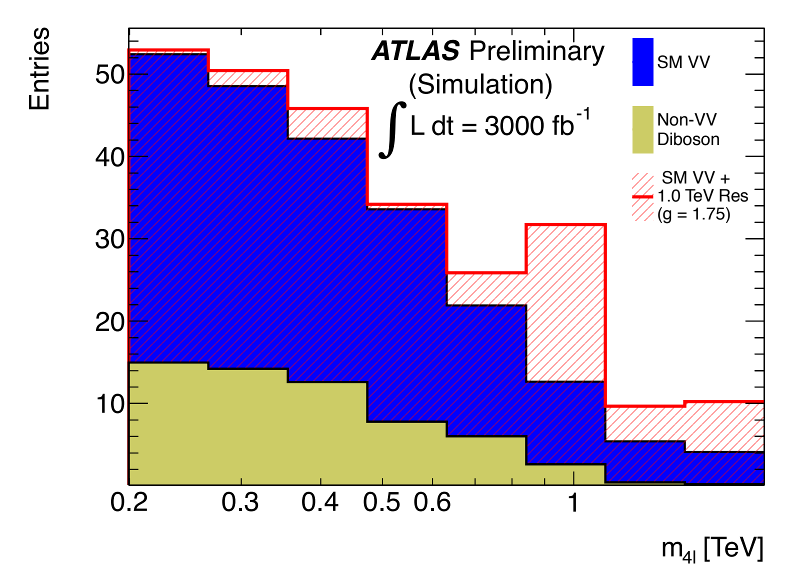
Vector Boson Scattering

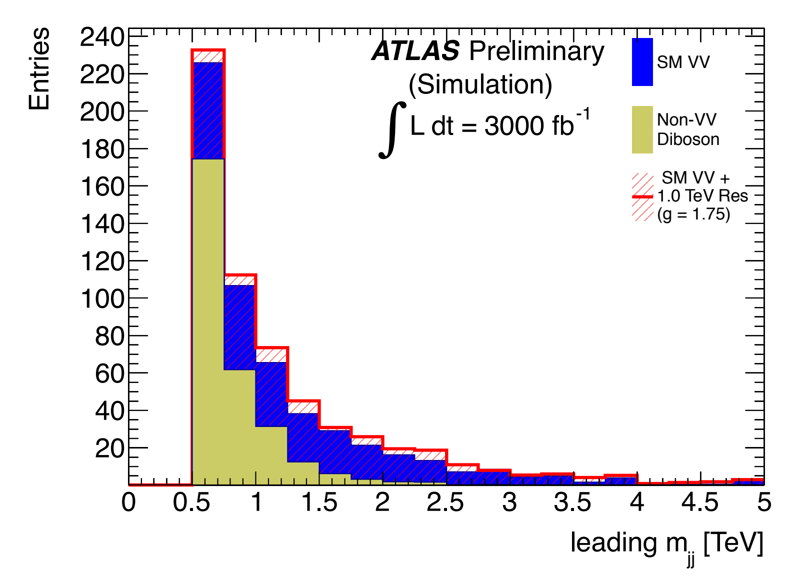
- In the Standard Model, the Higgs boson preserves the unitarity of scattering amplitudes in longitudinal Vector Boson Scattering (VBS)
- However new physics can contribute to the regularization of of the VBS cross-section or else enhancing it.
  - Example: in Technicolor models predict the appearance of resonances in the V-V invariant mass distribution
- ➔ the study of VBS properties at the LHC is a mandatory step to test the effects of the SM Higgs boson (if the existence will be confirmed) or from New Physics BSM.

Vector Boson Scattering

- At LHC VBS are tagged with two forward high-p_T jets on either side, the remnants of the quarks that have emitted the W/Z bosons in the central rapidity region: WW+2jets, WZ+2jets, ZZ+2jets
- ATLAS has performed preliminary studies of the process pp→ ZZjj → 4l+jj within the "Pade'" unitarization (IAM, Inverse Amplitude Method) and using the WHIZARD generator (it allows to generate weak boson scattering mediated by a new high-mass resonance in presence of a Higgs boson with 126 GeV mass)

ATL-PHYS-PUB-2012-005





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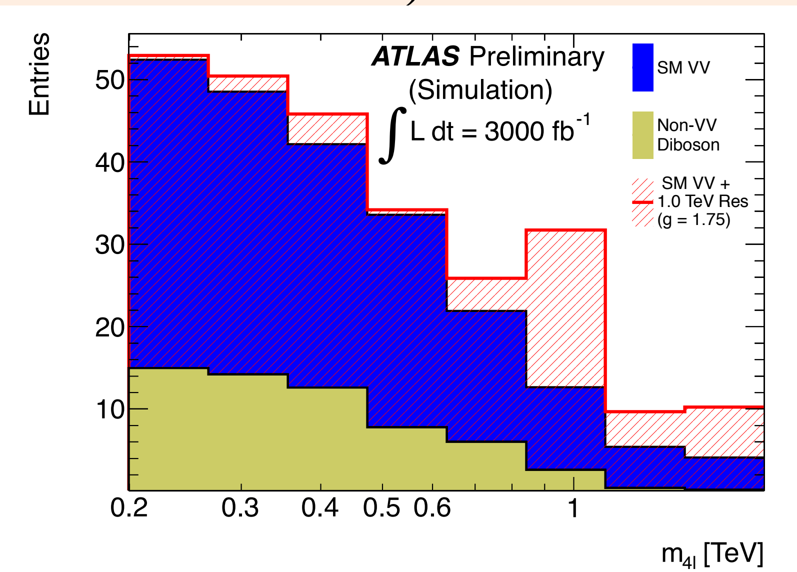


model	300 fb^{-1}	3000 fb^{-1}
$m_{\text{resonance}}$ = 500 GeV, $g = 1.0$	2.4σ	7.5σ
$m_{\text{resonance}}$ = 1 TeV, $g = 1.75$	1.7σ	5.5σ
$m_{\text{resonance}}$ = 1 TeV, $g = 2.5$	3.0σ	9.4σ

Summary of the expected sensitivity to anomalous VBS signal for a a few values of the mass of the resonance and of the coupling g.

Electroweak Physics

- The observation of a Higgs boson at 125 GeV is compatible with indirect constrains from Standard Model precision measurements of electroweak observables
- The SM can be challenged at LHC by precision measurements of Triple-Gauge Couplings (TGCs)
- In SM, EFT Lagrangian involving TGCs is described by 5 free parameters, assuming C and P invariance:
  - g_1^Z λ_γ λ_Z κ_γ κ_Z
  - in SM we have $g_1^Z = 1$; $\lambda_\gamma = \lambda_Z = \kappa_\gamma = \kappa_Z = 0$;

Electroweak Physics

- Final states of interest are $W\gamma$, $Z\gamma$, W^+W^- and $W^\pm Z$
- The experimental sensitivity to anomalous TGCs arises from the increase of cross-section production, or the alteration of kinematic distributions

Table 3: Predicted 95% confidence level constraints on anomalous triple-gauge couplings. Based on Ref. [3].

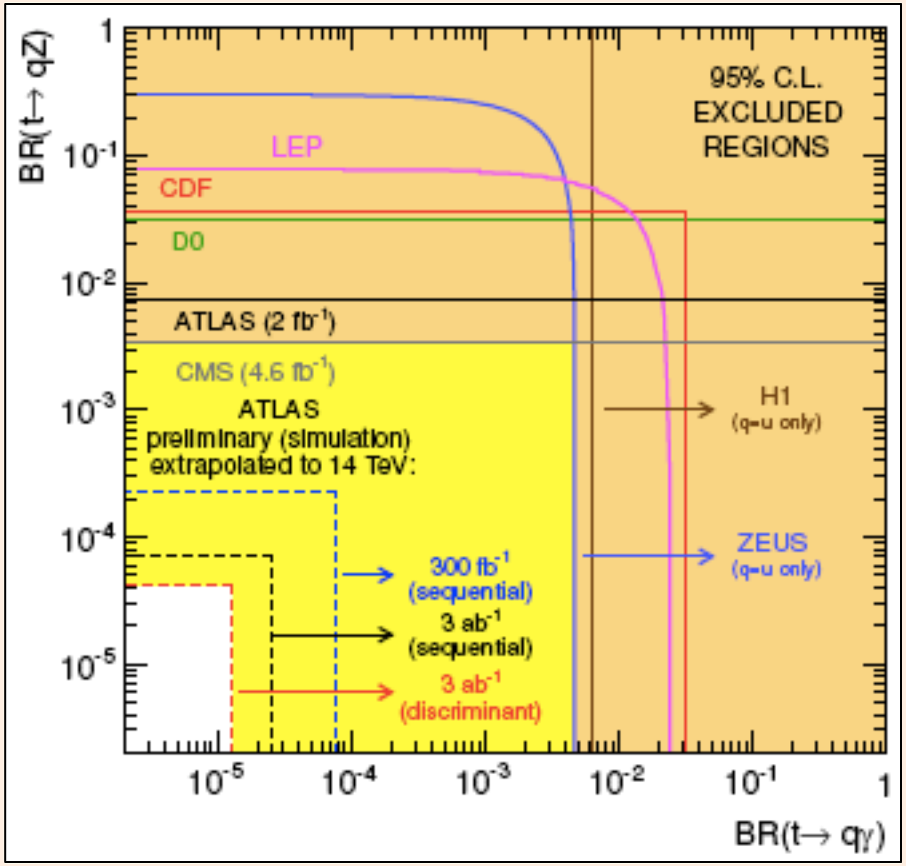
CMS

coupling	LHC	HL-LHC	HE-LHC
g_1^Z	0.0030	0.0019	0.0013
λ_γ	0.0009	0.0004	0.0004
λ_Z	0.0023	0.0014	0.0014
κ_γ	0.026	0.016	0.019
κ_Z	0.037	0.031	0.022

- a sensitivity at the 10^{-3} level is achievable
  - At this level BSM physics in radiative corrections should become visible
- form factors as big as Λ_{FF} = 10 TeV should be accessible

Top FCNC

- Absent at three level due to the GIM mechanism, the FCNC top quark decays, t→qγ, qZ, occurs in SM at loop level, BR ~ 10^{-12}
  - Best current 95% exclusion limits are 3.2% for t→qγ and 0.34% for t→qZ (q=u,c)
- Several SM extensions predict larger BRs, up to 10^{-4}
- Extrapolate current ATLAS searches to 14 TeV, 300 and 3000 fb^{-1}



Conclusions

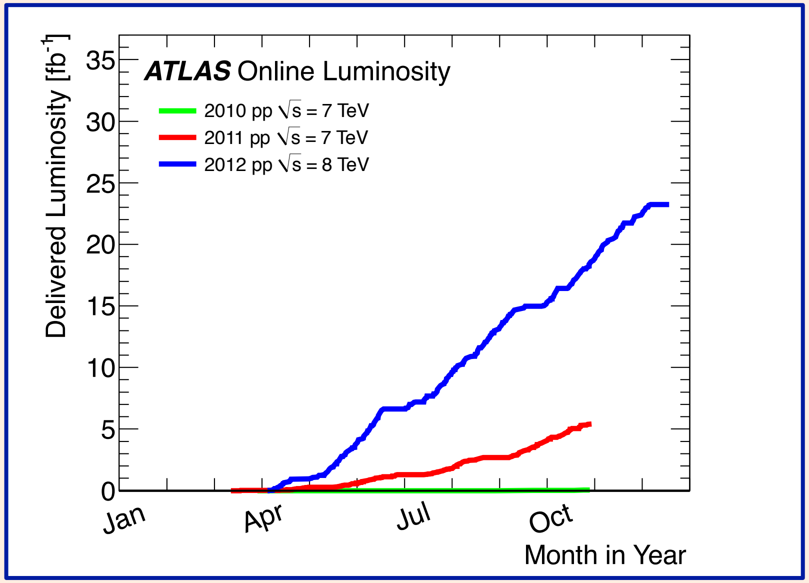
- A data sample of 300 fb^{-1} at the LHC will allow to exclude strong deviations of the Higgs boson recently discovered from predictions by Standard Model
- A complete investigation on the physics properties of this new boson will require the search for rare decay final states, selfcoupling processes, CP violation effects, as well as the reduction of experimental (and theoretical) uncertainties ➔ High-Luminosity LHC with L=3000 fb^{-1} can provide the required statistics with an accuracy on the Higgs couplings in the range of 1-4%;
- HL-LHC extends the searches of LHC of BSM physics, and offers the required data to study the properties of new particles if found at the LHC

outline

- Physics at the Large Hadron Collider
- Latest results from ATLAS and CMS on the recently discovered Higgs~~-like~~ particle
- Priorities after the discovery of the new boson: Higgs boson physics at the LHC and HL-LHC
- Conclusions

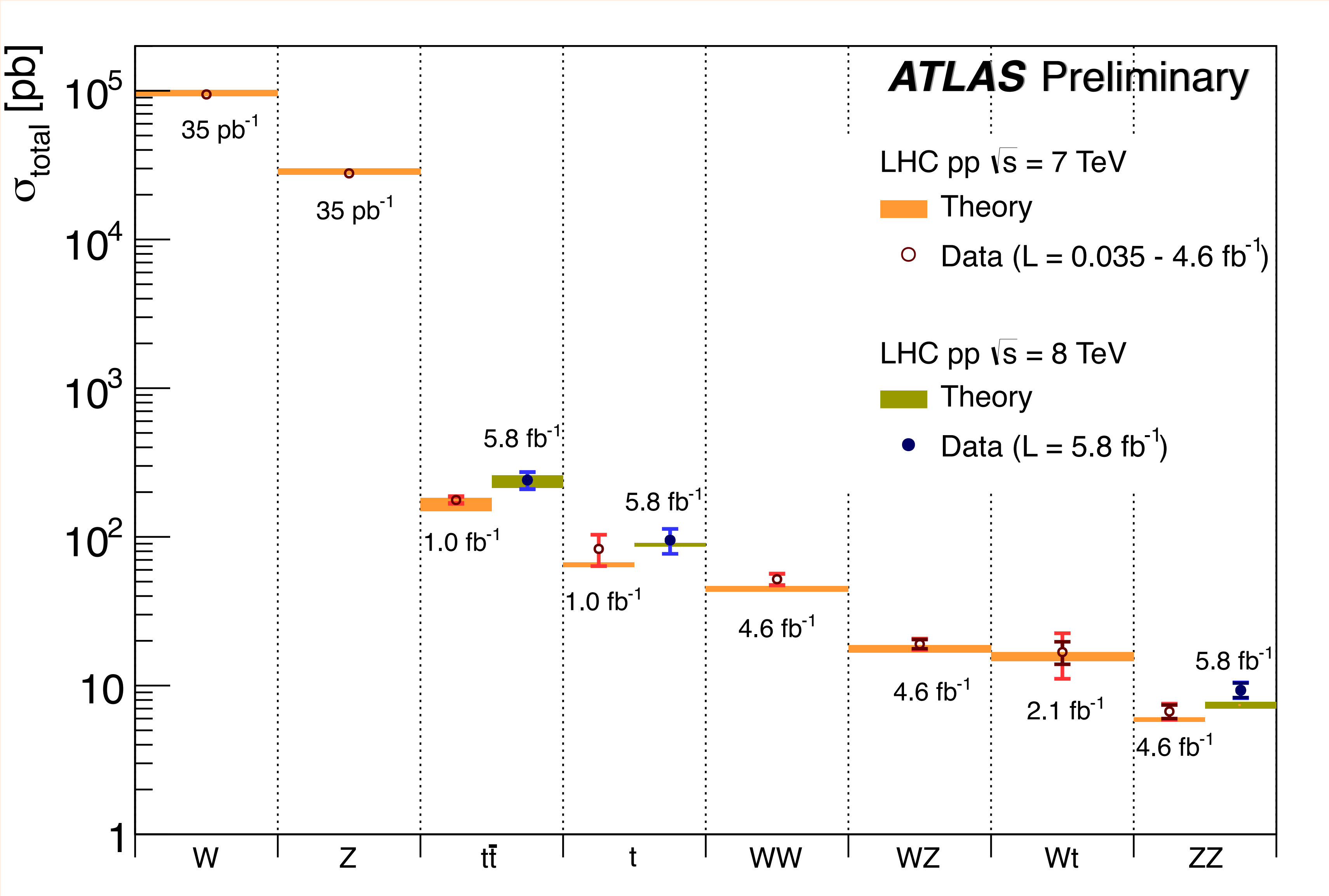
Physics at the Large Hadron Collider

- The LHC operations at high-energy started in 2010
- Excellent performance of the machine and of the four main experiments on the ring
- Collected in 2011 + 2012 about 5.5 fb^{-1} ($\sqrt{s}$ = 7 TeV) + 22 fb^{-1} ($\sqrt{s}$ = 8 TeV) by ATLAS and CMS

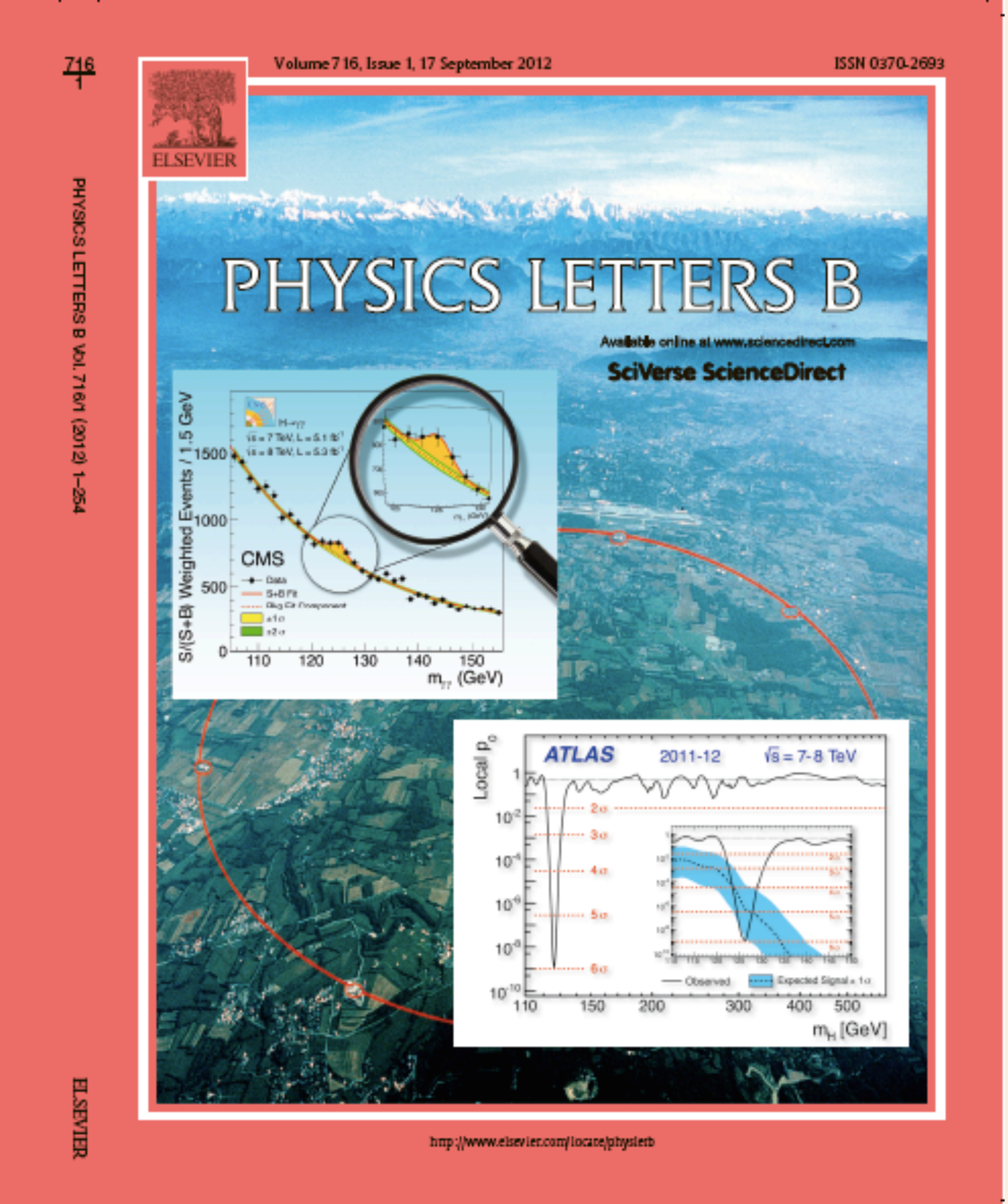


- A lot of solid outstanding experimental results are available:
- agreement between Standard Model (SM) and data in the EW and QCD sectors
- Discovery of a new particle, SM Higgs boson candidate, with mass around 125 GeV
- Exclusion of a wide range of parameters values in Supersymmetry (SUSY) models
- Exclusion of new heavy objects with mass up to 2-3 TeV

The successful Standard Model



The Standard Model predictions are confirmed by experimental data within uncertainties



ATLAS

[Physics Letters B](#)
[Volume 716, Issue 1](#), 17 September 2012, Pages 1–29

Results based on:
- 4.8 fb-1 of data at √s = 7 TeV
- 5.9 fb-1 of data at √s = 8 TeV

CMS

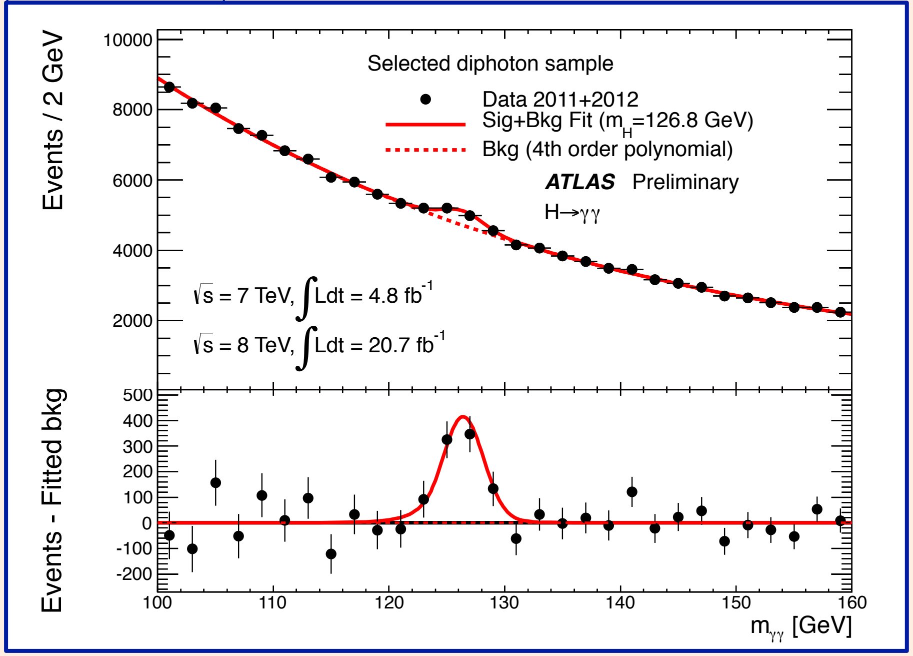
[Physics Letters B](#)
[Volume 716, Issue 1](#), 17 September 2012, Pages 30–61

Results based on:
- 5.1 fb-1 of data at √s = 7 TeV
- 5.3 fb-1 of data at √s = 8 TeV

channel	signature	S/B	Mass res.	ATLAS 2011+2012 (fb^{-1})	CMS 2011+2012 (fb^{-1})
$H \rightarrow \gamma\gamma$	Two high-p_T photons; Peak in inv. mass	few 10^{-2}	1-2%	5+20	5+20
$H \rightarrow ZZ^* \rightarrow 4l$	Four high-p_T leptons; Peak in inv. mass	≥ 1	1-2%	5+20	5+20
$H \rightarrow WW^* \rightarrow l\nu l\nu$	two high-p_T leptons + MET; Transverse mass	few 10^{-1}	-	5+20	5+20
$H \rightarrow \tau\tau$	2 high-p_T leptonts/ hadronic-τs + MET; inv. mass	few 10^{-2}	~20%	5+13	5+20
$H \rightarrow bb$	Two high-p_T b-jets in assoc. with W or Z; Inv. mass	few 10^{-2}	10-16%	5+13	5+12
Combination				Moriond 13	HCP 12

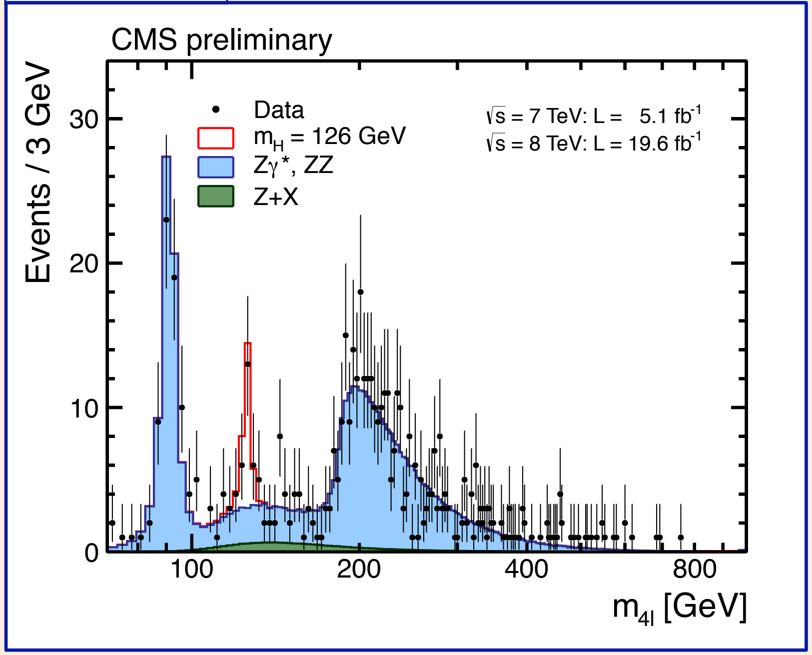
Latest results from ATLAS and CMS

ATL-CONF-2013-012



Invariant mass distribution of diphoton candidates for the combined √s= 7 TeV and √s= 8 TeV data samples. The fit to the data is the sum of a signal component fixed to m_H = 126.8 GeV and a background component described by a fourth-order Bernstein polynomial. Bottom inset: display of the residuals of the data with respect to the fitted background.

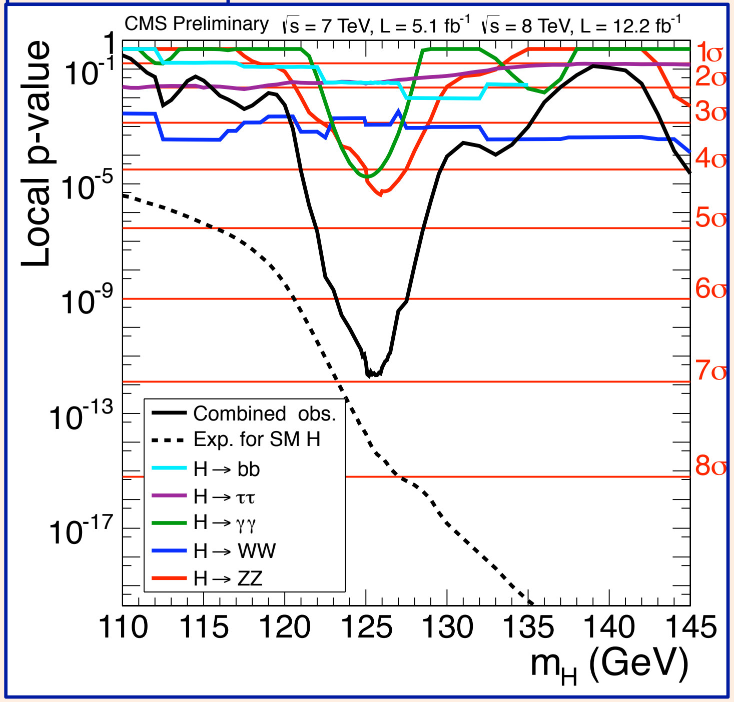
CMS PAS HIG-13-002



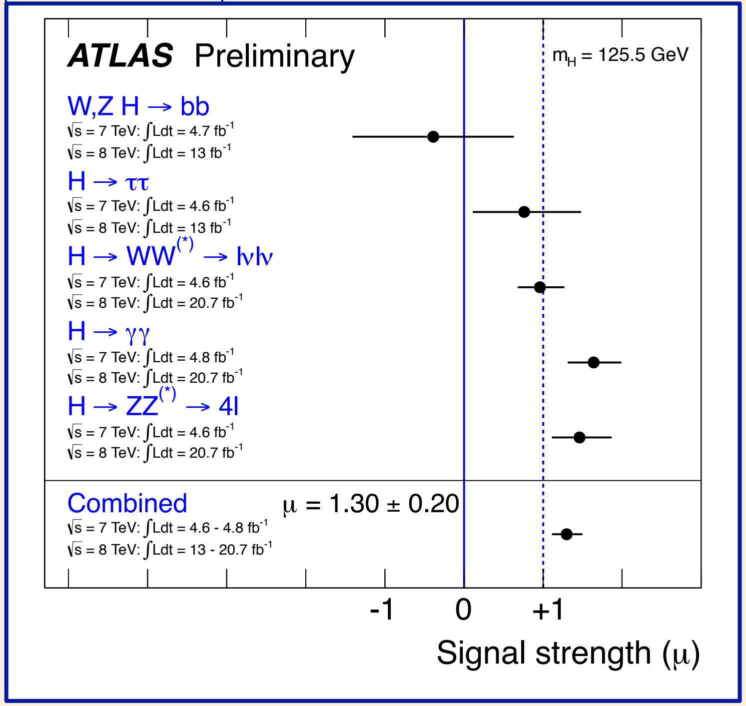
Four-lepton reconstructed mass for the sum of the 4e, 4μ, and 2e2μ channels. Points represent the data, shaded histograms represent the background and unshaded histogram the signal expectations

Latest results from ATLAS and CMS

CMS PAS HIG-12-045



ATL-CONF-2013-034



The observed local p-value for the five decay modes and the overall combination as a function of the SM Higgs boson mass in the range 110–1000 GeV (left) and 110–145 GeV (right). The dashed lines show the expected local p-values for a SM Higgs boson with a mass m_H.

Local significance: 6.9 σ (CMS – up to 5+12 fb^{-1})

Local significance: ~10 σ (ATLAS – up to 5+21 fb^{-1})

Measurements of the signal strength parameter mu for mh at 125.5 GeV for the individual channels and their combination.

$\mu = 1.30 \pm 0.20$ for $m_H = 125.5$ GeV

Many details in Higgs talks at this Workshop

Physics at HL-LHC

- On the basis of what discussed in the previous slides, ATLAS and CMS presented two documents for the Symposium in Cracow, subsequently updated in October 2012 for the Briefing Book
- These documents focused on:
  - **Higgs couplings, self-couplings, CP**
  - Vector Boson Scattering
  - SUSY
  - Exotics
  - SM: Vector Boson TGCs and top quark FCNC

The LHC → HL-LC Upgrade

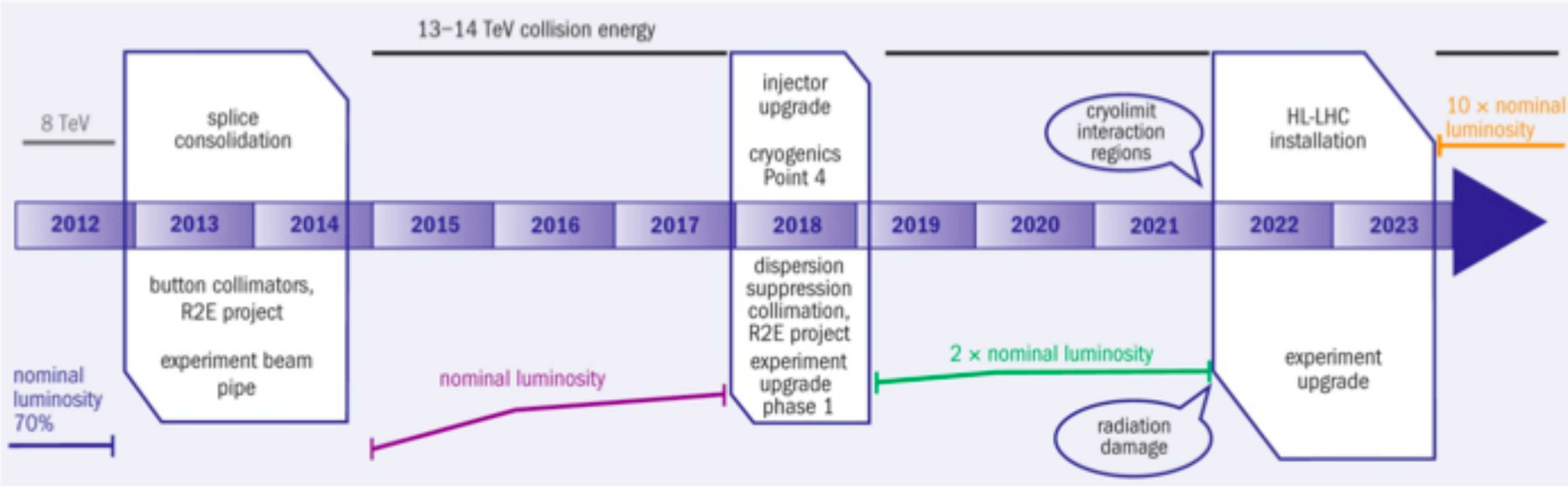


Figure 1: LHC baseline plan for the next ten years. In terms of energy of the collisions (upper line) and of luminosity (lower lines). The first long shutdown 2013-14 is to allow design parameters of beam energy and luminosity. The second one, 2018, is for secure luminosity and reliability as well as to upgrade the LHC Injectors.

The LHC → HL-LC Upgrade

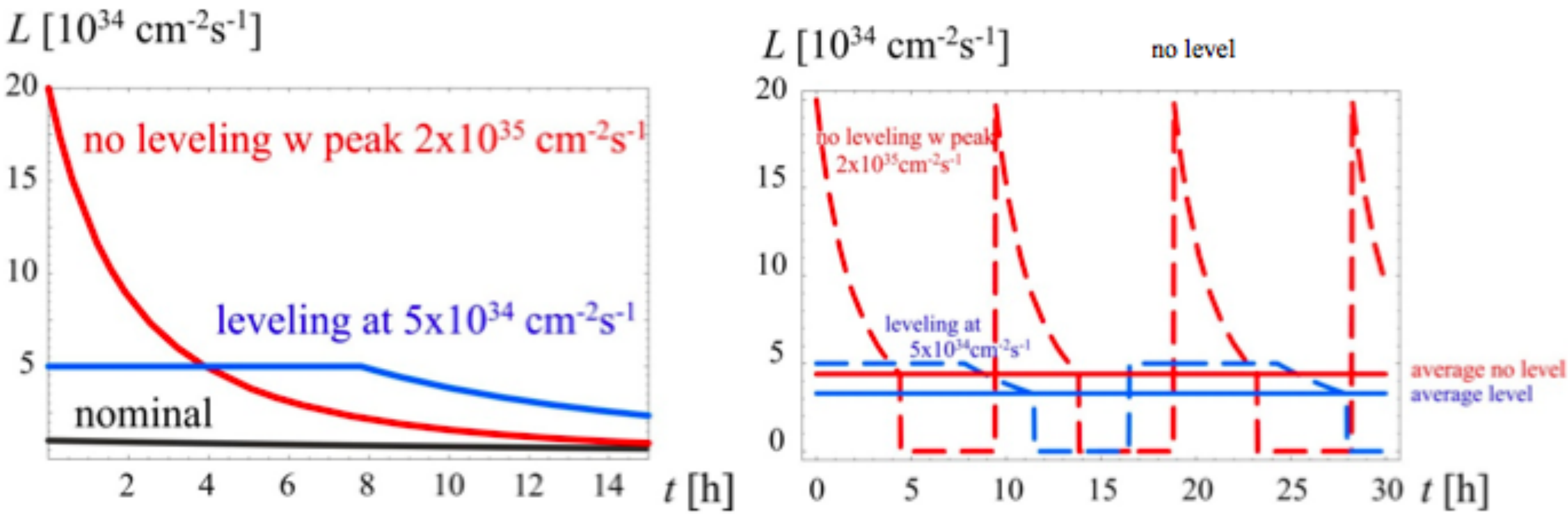


Figure 2.3: Left: luminosity profile for a single long run starting at nominal peak luminosity (black line), with upgrade no levelling (red line) with levelling (dotted line). Right: luminosity profile with optimized run time, without and with levelling (blue and red dashed lines), and average luminosity in both cases (solid lines).

The LHC → HL-LC Upgrade

Table 2. Summary of the cost of HL-LHC with split between Consolidation and full performance.

	Improving Consolidation	Full performance	Total HL-LHC
Mat. (MCHF)	476	360	**836**
Pers. (MCHF)	182	31	**213**
Pers. (FTE-y)	910	160	**1070**
TOT (MCHF)	658	391	**1,049**

The European Strategy Preparatory Group

R. Aleksan, P. Braun-Munzinger, Ph. Chomaz, K. Desch, C. De Clercq, M. Diemoz, K. Huitu, P. Jenni, M. Krammer, Y. Kuno, P. McBride, T. Nakada, E. Tsesmelis, D. Wark, A. F. Żarnecki, and F. Zwirner

European Strategy for Particle Physics Preparatory Group

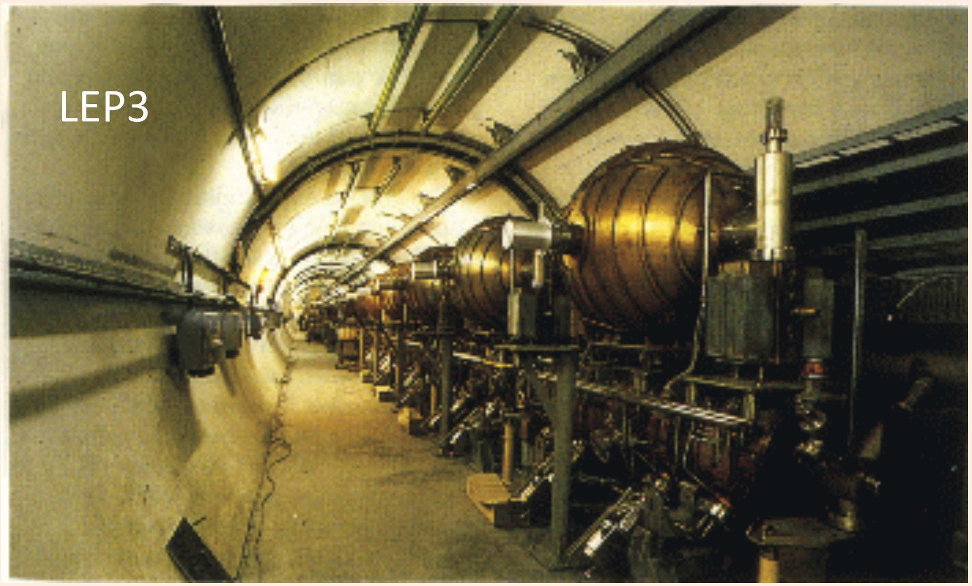
and

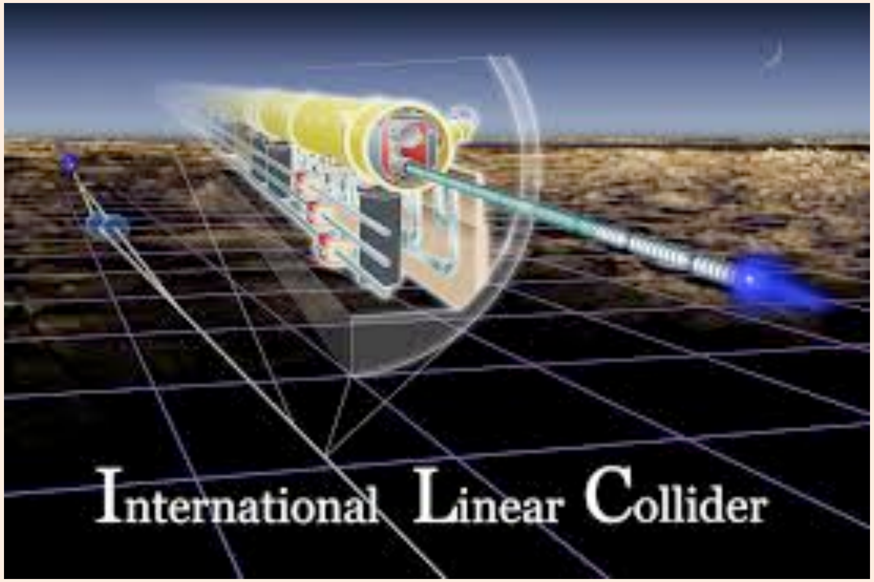
P. Brun, E. Fernandez Martinez, R. Forty, E. Garutti, K. Kutak, A. Lister, P. Slavich, and F. Zimmermann

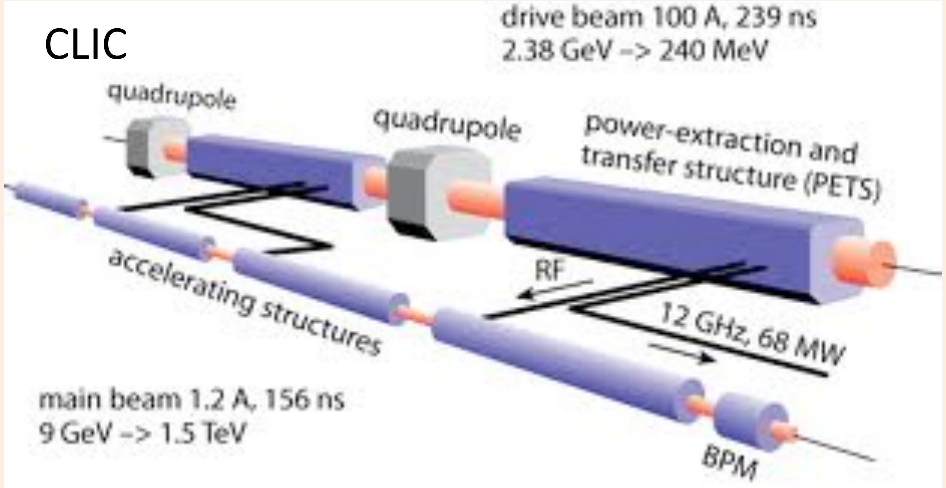
Scientific Secretaries for the Open Symposium in Cracow, Poland

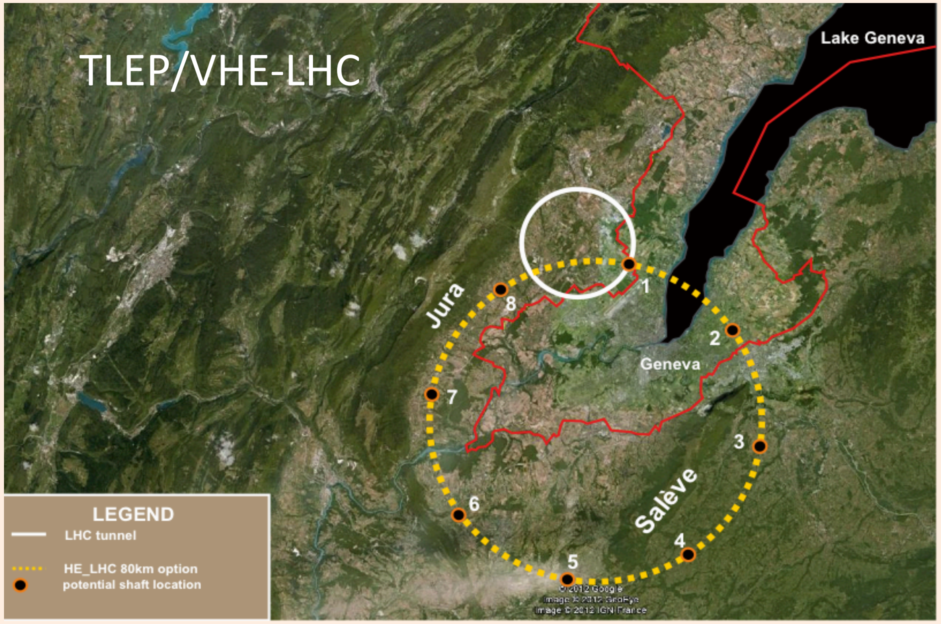
Some proposals for future colliders

See also: arxiv:1302.3318

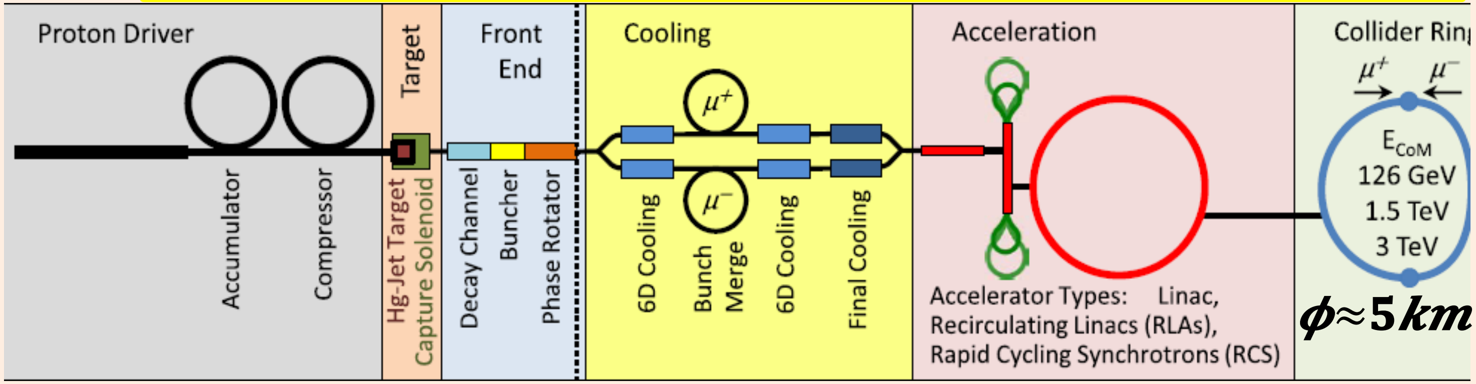








From ν-factories toward the "dream" of muon collider



Some ultra-challenging components:

- **Very high field solenoids (>30T)**
- **High gradient cavities in multi-Tesla field**

Require much smaller beam size (i.e. lower emittance)
Very efficient cooling →

Recommendations from European Strategy Group (cont'd)

High-priority large-scale scientific activities

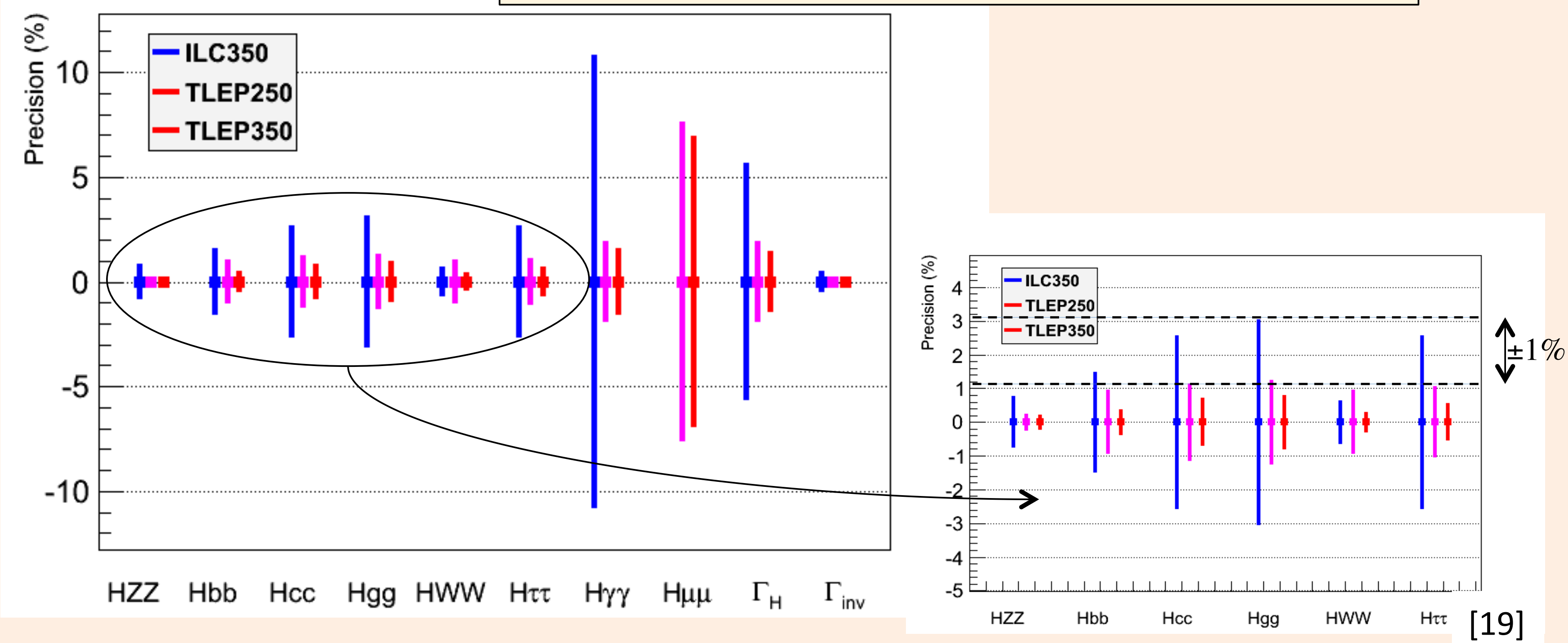
Recommendation #4

f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading neutrino projects in the US and Japan.*

Higgs couplings for Precision Higgs Factories

- Same conclusion when Γ_H is a free parameter in the fit
  - Plot shown only for ILC350 and TLEP, with an accurate width measurement

$$\sigma_{HZ} \propto g^2_{HZZ}, \text{ and } \sigma_{HZ} \times \mathrm{BR}(H \rightarrow XX) \propto g^2_{HZZ} g^2_{HXX} / \Gamma_H$$



[19]

TLEP : sub-percent precision, adequate for NP sensitivity beyond 1 TeV

by Patrick Janot

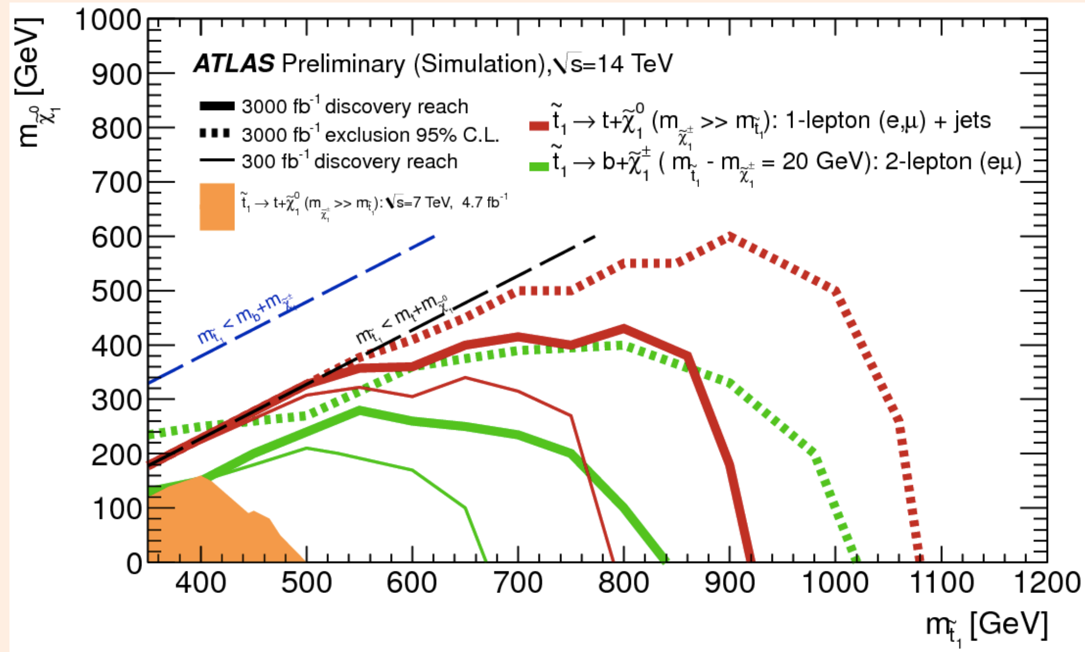
SUSY Searches

- So far there has been no sign of Supersymmetry at LHC
  - However only < 10% of the LHC expected data have been studied (and at $\sqrt{s}=7$ TeV)
  - 3rd generation squarks have low cross-sections
- If we find it:
  - We have a large set of new particles to study
  - Thus a SUSY discovery will mandate more luminosity
- If will not find it by 2020:
  - HL-LHC offers a 25% increase in mass reach
  - HL-LHC will explore a phase space no other machine will probe for decades

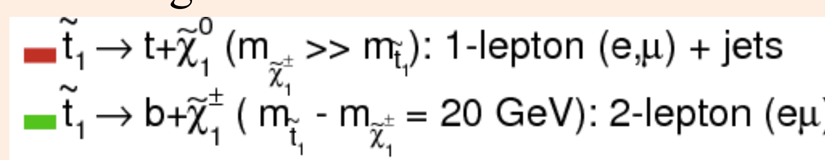
Searches for stop

ATL-PHYS-PUB-2013-001

- Probably this will be one of the most important points in SUSY for the immediate future: naturalness requires stop mass not larger than ~ 1 TeV
- Rates will be modest ➔ HL-LHC represents an ideal machine for this search



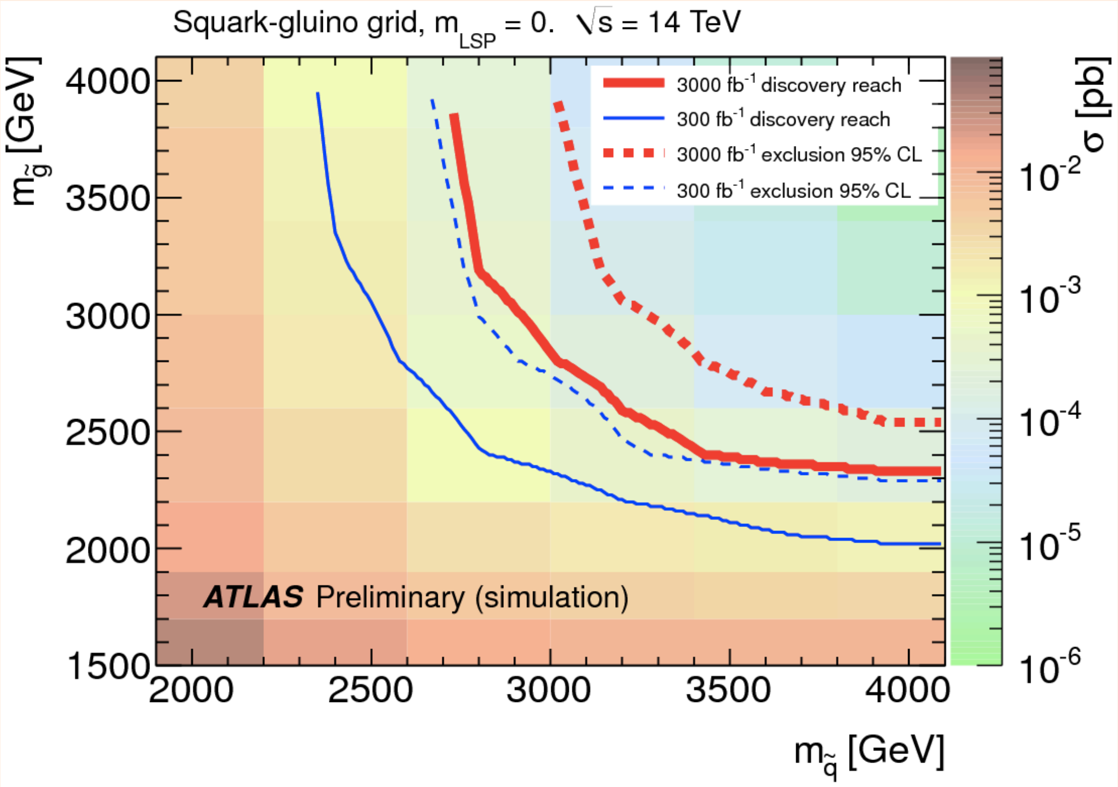
The 95% CL exclusion limits for 3000 fb^{-1} (dashed) and 5 sigma discovery reach (solid) for 300 fb^{-1} and 3000 fb^{-1} in the stop, neutralino_1 mass plane assuming:



Searches for squarks and gluinos

- HL-LHC gives tight limits:
  - ~ 3 TeV for squarks
  - ~ 2.5 TeV for gluinos
- This represents a 400 GeV rise in sensitivity with respect to the L=300 fb^{-1} case

ATL-PHYS-PUB-2013-001

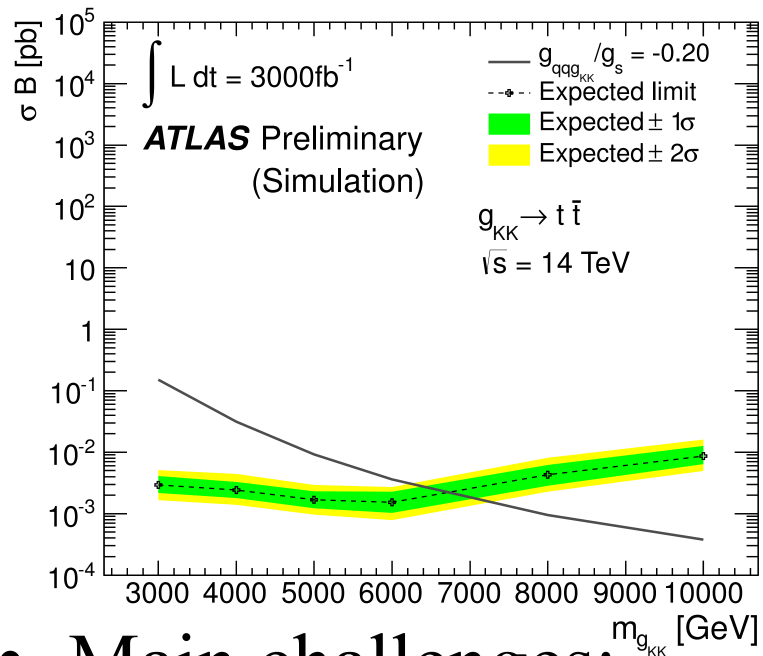


The 95% CL exclusion limits (solid lines) and 5 sigma discovery reach (dashed lines) in a simplified squark--gluino model with massless neutralino with 300 fb-1 (blue lines) and 3000 fb-1 (red lines). The colour scale shows √s=14 TeV NLO production cross section calculated by Prospino 2.1.

Exotics Searches

ATL-PHYS-PUB-2013-003

- Searches for ttbar resonances or Z' leptons can exploit the physics potential offered by HL-LHC



model	$300\,\mathrm{fb}^{-1}$	$1000\,\mathrm{fb}^{-1}$	$3000\,\mathrm{fb}^{-1}$
g_{KK}	4.3 (4.0)	5.6 (4.9)	6.7 (5.6)
$Z'_{\mathrm{Topcolour}}$	3.3 (1.8)	4.5 (2.6)	5.5 (3.2)
$Z'_{SSM} \rightarrow ee$	6.5	7.2	7.8
$Z'_{SSM} \rightarrow \mu\mu$	6.4	7.1	7.6

Summary of the expected limits for g_{KK}→ ttbar and $Z'_{Topcolor}$→ttbar searches in the lepton+jets (dilepton) channel and of Z'_{SSM} → ee and Z'_{SSM}→ μμ searches in the Sequential Standard Model. All boson mass limits are quoted in TeV.

- Main challenges:
  - Reconstruct highly boosted top decays
  - Ensure lepton measurement at very high pT
    - Muon system alignment
    - Leakage from calorimeter (?)

ERICE (Sicily)

Update of the European Strategy for Particle Physics

Roy Aleksan
HF-Frascati
Feb. 14, 2013

Habemus Strategiam!

17 recommendations have been issued:
https://indico.cern.ch/getFile.py/access?resId=0&materialId=0&confId=217656
They have still to be endorsed by the CERN Council (March 20).

Recommendations from European Strategy Group

Roy Aleksan
HF-Frascati
Feb. 14, 2013

High-priority large-scale scientific activities

Recommendation #1

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

Recommendations from European Strategy Group (cont'd)

Roy Aleksan
HF-Frascati
Feb. 14, 2013

High-priority large-scale scientific activities

Recommendation #2

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*

Recommendations from European Strategy Group (cont'd)

Roy Aleksan
HF-Frascati
Feb. 14, 2013

High-priority large-scale scientific activities

Recommendation #3

e) There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*