ATLAS Upgrade
Physics Perspectives

Discovery strategy meeting

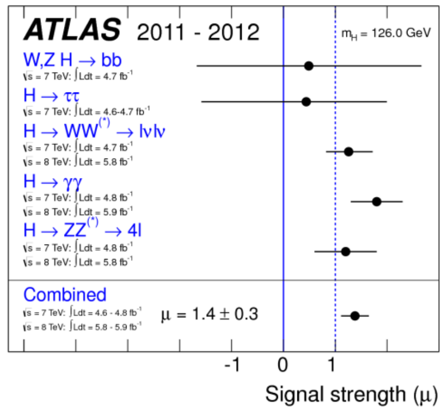
J.B.Hansen / ATLAS

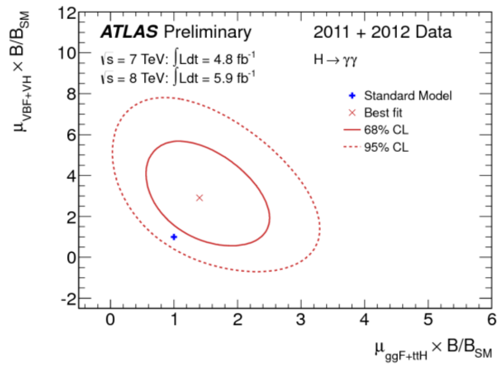
November 2012

Motivation for upgrade

Discovery of the X (125 GeV) Higgs Candidate

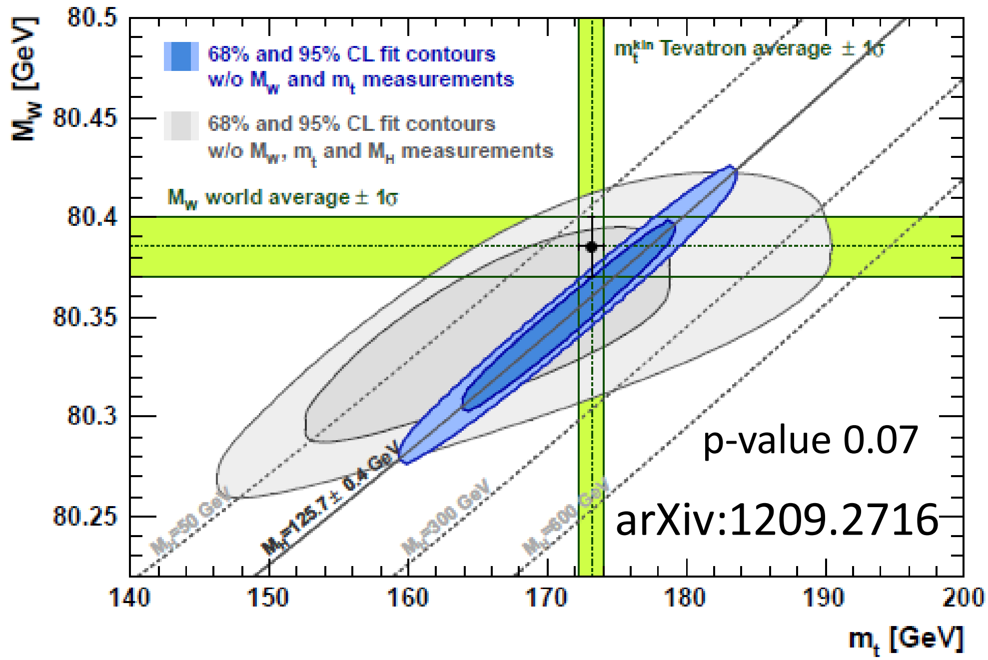
- Most likely the Higgs boson is found. What is the next?
  - Is this the Standard Model Higgs?
  - Is there anything else?
- Due to its nature the Higgs boson couples to all the (massive) particles and therefore we have the tool to search physics Beyond the Standard Model.





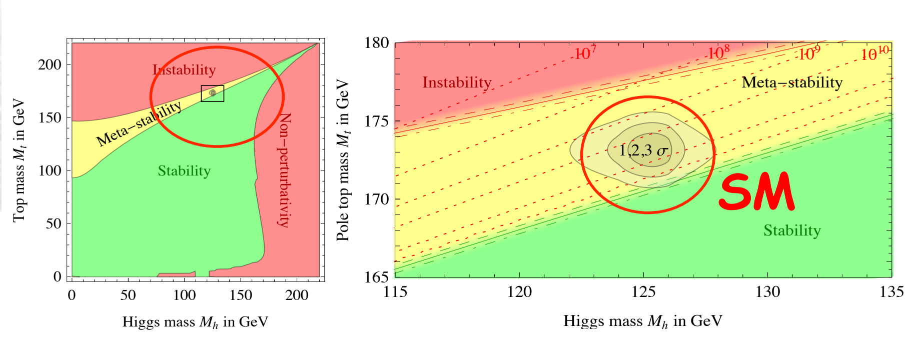
The adventure in the TeV energy regime has just begun!

- Very few "BSM hints" at this point (G. Dissertori):
  - Top AFB at Tevatron (2-3 sigma)
  - W+b x-section slightly high
  - Di-boson x-section slightly high
  - Tension between bb and l+l- AFB's in Z decay
  - Does H→ZZ agree with H→γγ

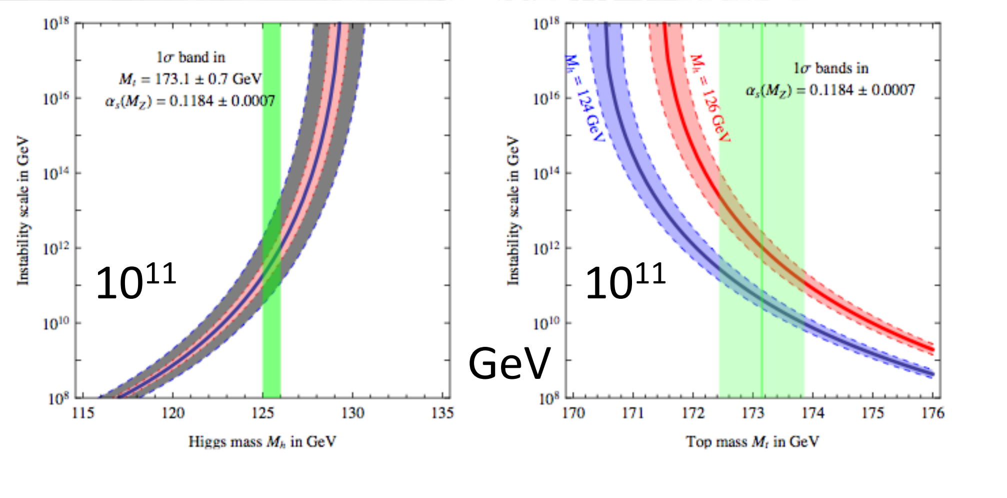


Do we have a hint from Nature?

- No! A Higgs mass of 125 GeV is a very special value
- From **metastability** considerations
  - SM Higgs with **M_h = 125 GeV does not imply a strict upper bound on the** scale of new



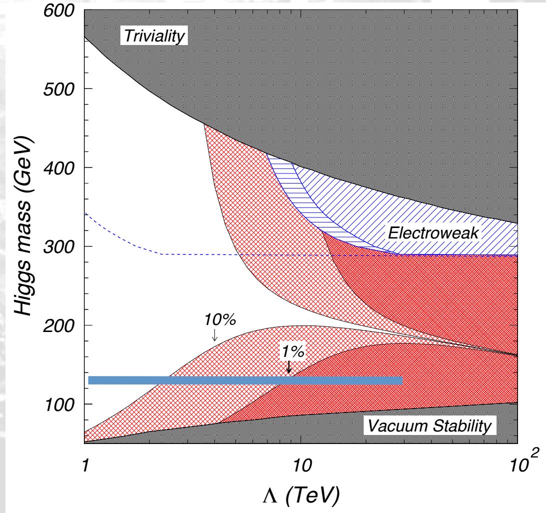
G.Degrassi, S. Di Vita, J.EM, J. Espinosa, G.F. Giudice, G. Isidori, A. Strumia. (tomorrow in arXiv)



G.Degrassi, S. Di Vita, J.EM, J. Espinosa, G.F. Giudice, G. Isidori, A. Strumia. (tomorrow in arXiv)

- Fine-tuning may provide a weak hint to a scale

  No need for new physics up to well beyond Λ = 10 TeV



- Precision measurements + Higgs particle may be our only window

  → **Precision** combined with **energy**

The LHC Timeline

LS=Long Shutdown

Year	Phase	Event	Integrated luminosity
2009		LHC start up, $\sqrt{s}$ = 900 GeV	
2010			
2011		$\sqrt{s}$ = 7-8 TeV , L = 6 to 8•10^{33} $cm^{-2}s^{-1}$, bunch spacing **50 ns**	
2012			~25 fb^{-1}
2013	LS1	Go to design energy, nominal luminosity	
2014			
2015		$\sqrt{s}$ = 13-14 TeV, L = 1•10^{34} $cm^{-2}s^{-1}$, bunch spacing **25 ns** **(likely to be more)**	
2016			
2017			~50 fb^{-1}
2018	LS2	Injector & LHC Phase I upgrade to full design luminosity	
2019			
2020		$\sqrt{s}$ = 14 TeV, L = 2•10^{34} $cm^{-2}s^{-1}$, bunch spacing **25 ns** **(likely to be more)**	
2021			~300 fb^{-1}
2022	LS3	HL-LHC Phase-2 upgrade, crab cavities?, IR	
2023		$\sqrt{s}$ = 14 TeV, L = 5•10^{34} $cm^{-2}s^{-1}$, bunch spacing **25 ns** **Plan for 50% more**	
2030?			~3000 fb^{-1}

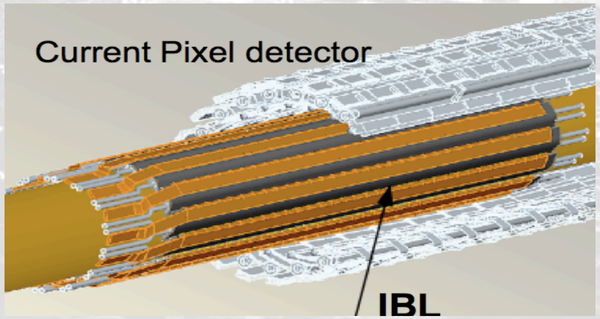
Discovery 2: 2 x Energy and 10 x Luminosity

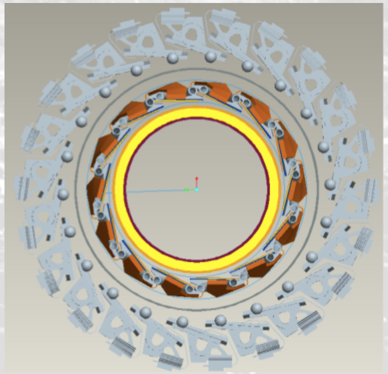
Phase-0 (installation 2013-14)

Main Improvements to Physics Capabilities

1. New small Be pipe
2. New insertable pixel b-layer (IBL) (drives shutdown schedule)
3. Finish the installation of the EE muon chambers staged in 2003 +additional chambers in the feet (new electronics) and elevators region
4. Add topological processing in level 1 of trigger
5. **Improve L1 trigger readout rate to 100kHz – NBI group**

IBL preserves current physics performance at high pileup <μ>=46



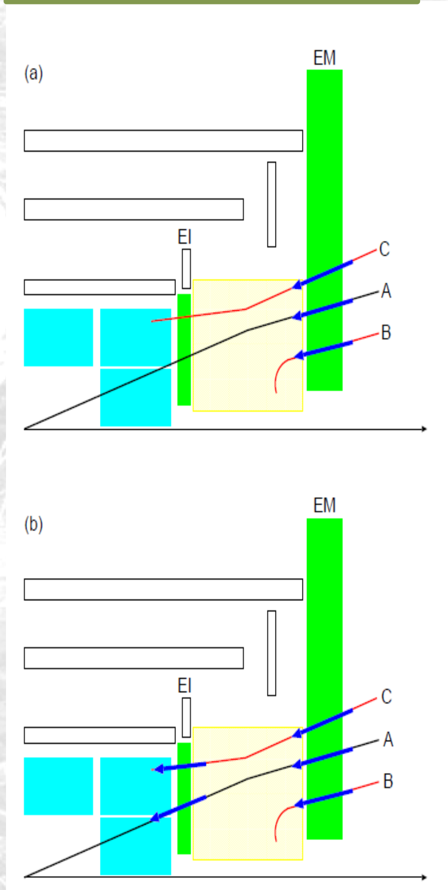


Phase-I (installation in 2018)

Major Projects

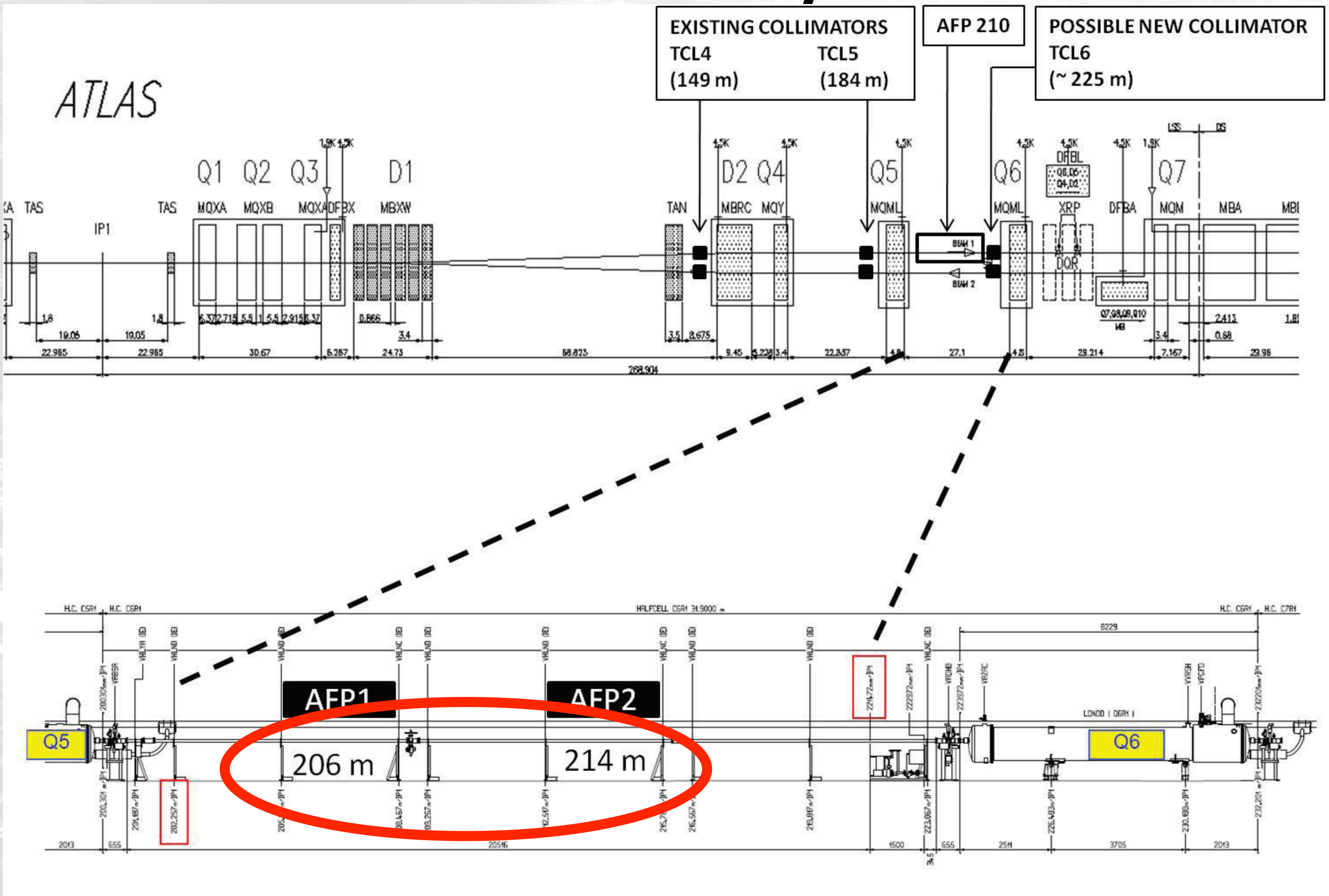
1. New muon small wheels **with more trigger granularity and trigger track vector information – NBI**
2. Higher-granularity calorimeter LVL1 trigger and associated front-end electronic
3. Fast track processor (FTK) using SCT and pixel hits (input to LVL2) expected installation before 2018
4. **Forward physics detection station at 220m for new diffractive physics (full 3D edgeless and timing detectors, target 2017) – NBI**
5. Topological trigger processors combining LVL1 information from different regions of interest (**improvements starting well before 2018 – NBI**)

New muon small wheel



B and C background

ATLAS Forward Physics detector



No hardware involvement from NBI – but plentiful "invitations"

Physics Potential of LHC14

- Electroweak Physics
  - Production of multiple gauge bosons ($n_V \geq 3$)
    - triple and quartic gauge boson couplings
  - Top quarks/rare decays
- Higgs physics
  - Rare decay modes
  - Higgs couplings to fermions and bosons
  - Higgs self-couplings
  - Heavy Higgs bosons of the MSSM
- Supersymmetry
- Extra Dimensions
  - Direct graviton production in ADD models
  - Resonance production in Randall-Sundrum models TeV^{-1} scale models
  - Black Hole production
- Quark substructure
- Strongly-coupled vector boson system
  - $W_L Z_L$ g $W_L Z_L$, $Z_L Z_L$ scalar resonance, $W^+_L W^+_L$
- New Gauge Bosons

Examples studied in some detail

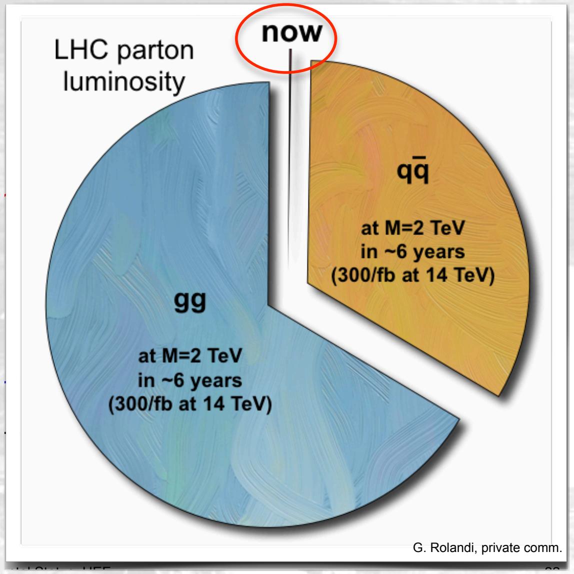
CERN-TH/2002-078
hep-ph/0204087
April 1, 2002

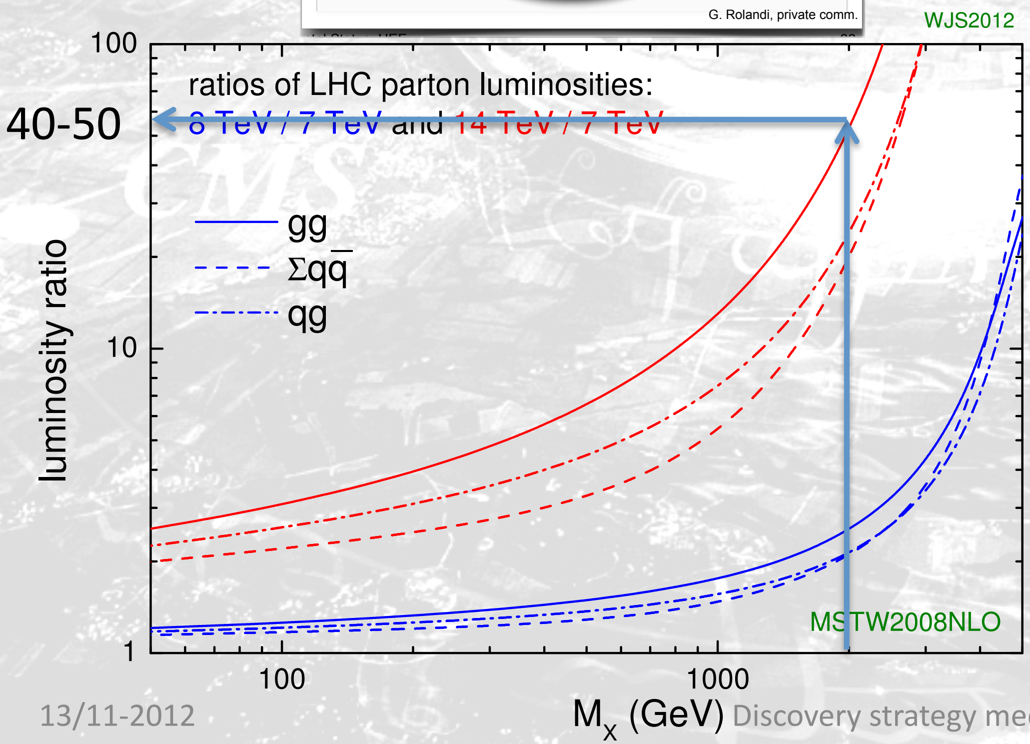
PHYSICS POTENTIAL AND EXPERIMENTAL CHALLENGES OF THE LHC LUMINOSITY UPGRADE

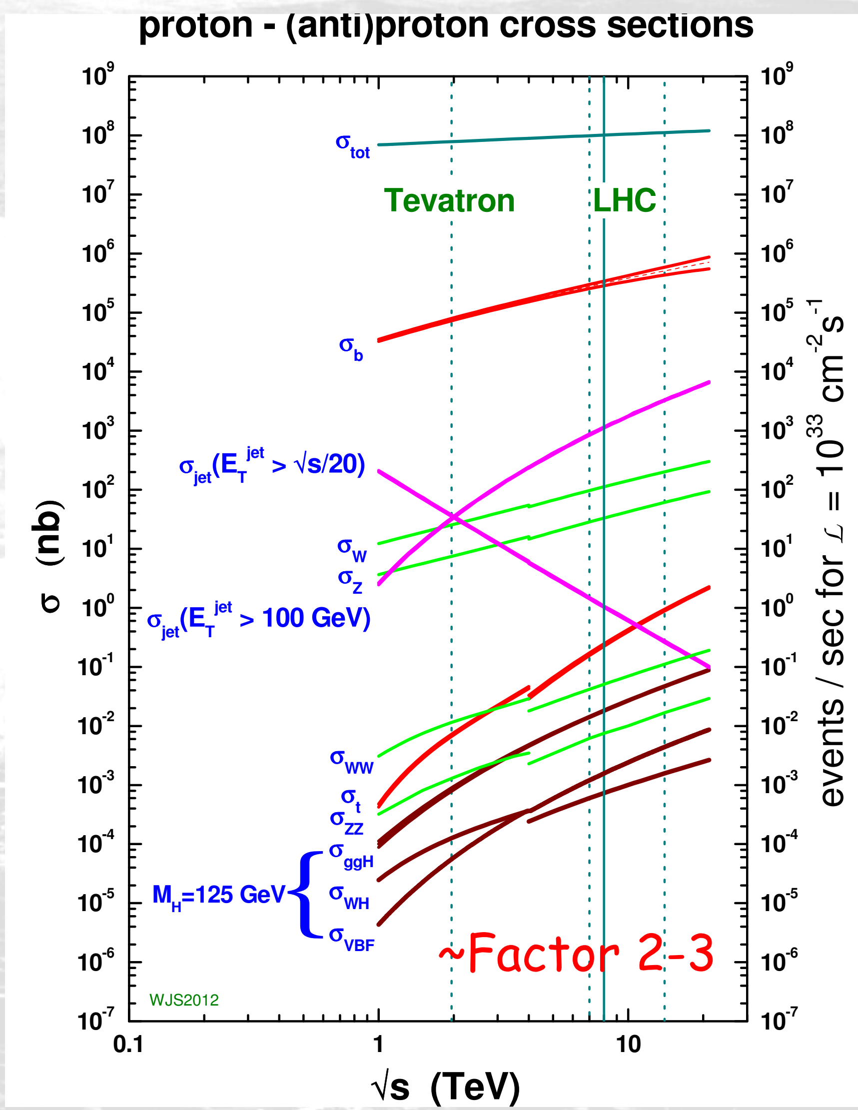
Conveners: F. Gianotti [1], M.L. Mangano [2], T. Virdee [1,3]
Contributors: S. Abdullin [4], G. Azuelos [5], A. Ball [1], D. Barberis [6], A. Belyaev [7], P. Bloch [1], M. Bosman [8], L. Casagrande [1], D. Cavalli [9], P. Chumney [10], S. Cittolin [1], S.Dasu [10], A. De Roeck [1], N. Ellis [1], P. Farthouat [1], D. Fournier [11], J.-B. Hansen [1], I. Hinchliffe [12], M. Hohlfeld [13], M. Huhtinen [1], K. Jakobs [13], C. Joram [1], F. Mazzucato [14], G.Mikenberg [15], A. Miagkov [16], M. Moretti [17], S. Moretti [2,18], T. Niinikoski [1], A. Nikitenko [3,†], A. Nisati [19], F. Paige [20], S. Palestini [1], C.G. Papadopoulos [21], F. Piccinini [2,‡], R. Pittau [22], G. Polesello [23], E. Richter-Was [24], P. Sharp [1], S.R. Slabospitsky [16], W.H. Smith [10], S. Stapnes [25], G. Tonelli [26], E. Tsesmelis [1], Z. Usubov [27,28], L. Vacavant [12], J. van der Bij [29], A. Watson [30], M. Wielers [31]

hep-ph/0204087

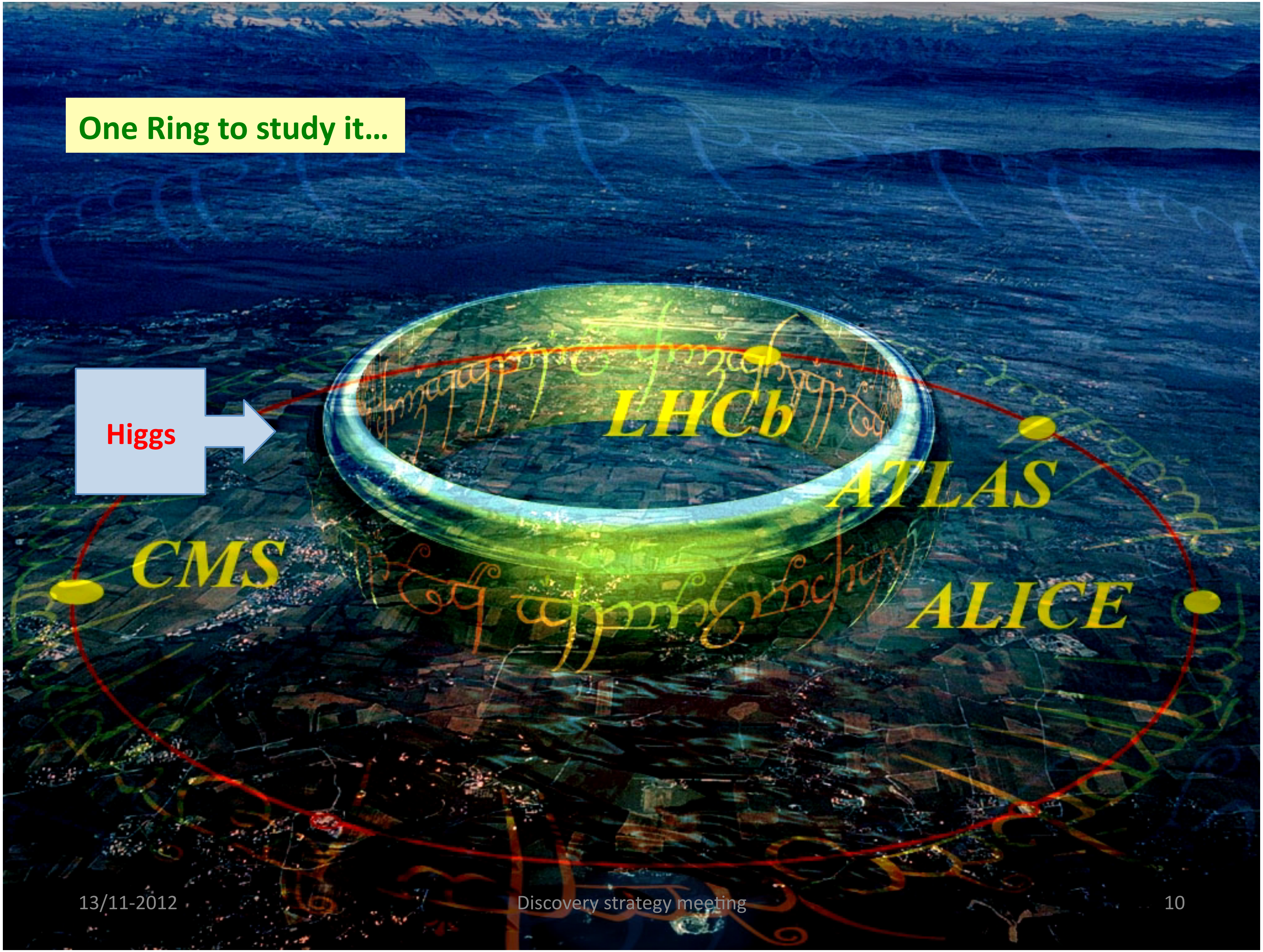
Physics Potential of LHC14







One Ring to study it…



Higgs Properties

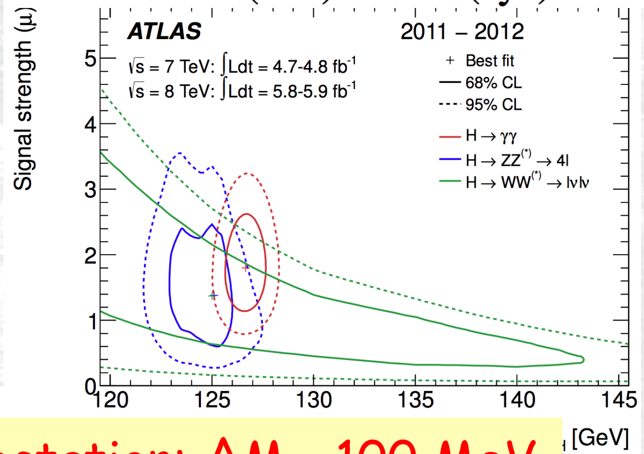
Checklist:

Discovery 1

- **Mass**
- Spin and parity (J^P)
- Couplings to vector bosons: is this boson related to EWSB, and how much does it contribute to restoring unitarity in $W_L W_L$ scattering
- Couplings to fermions (>3σ)
  - is Yukawa interaction at work
  - contribution to restoring unitarity?
- Couplings proportional to mass as in SM?
- Is there only one unique state, or more?
- Elementary or composite?
- Self-interaction
- CP (even, odd, or admixture?)

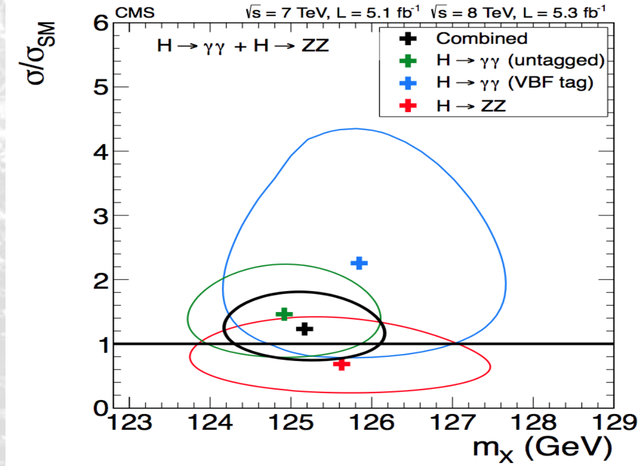
  →With 300/fb at 14 TeV the full **CP quantum numbers of non-mixed states can finally be established**

$126.0 \pm 0.4\ (\text{stat}) \pm 0.4\ (\text{sys})$ GeV



Expectation: ΔM_h~100 MeV

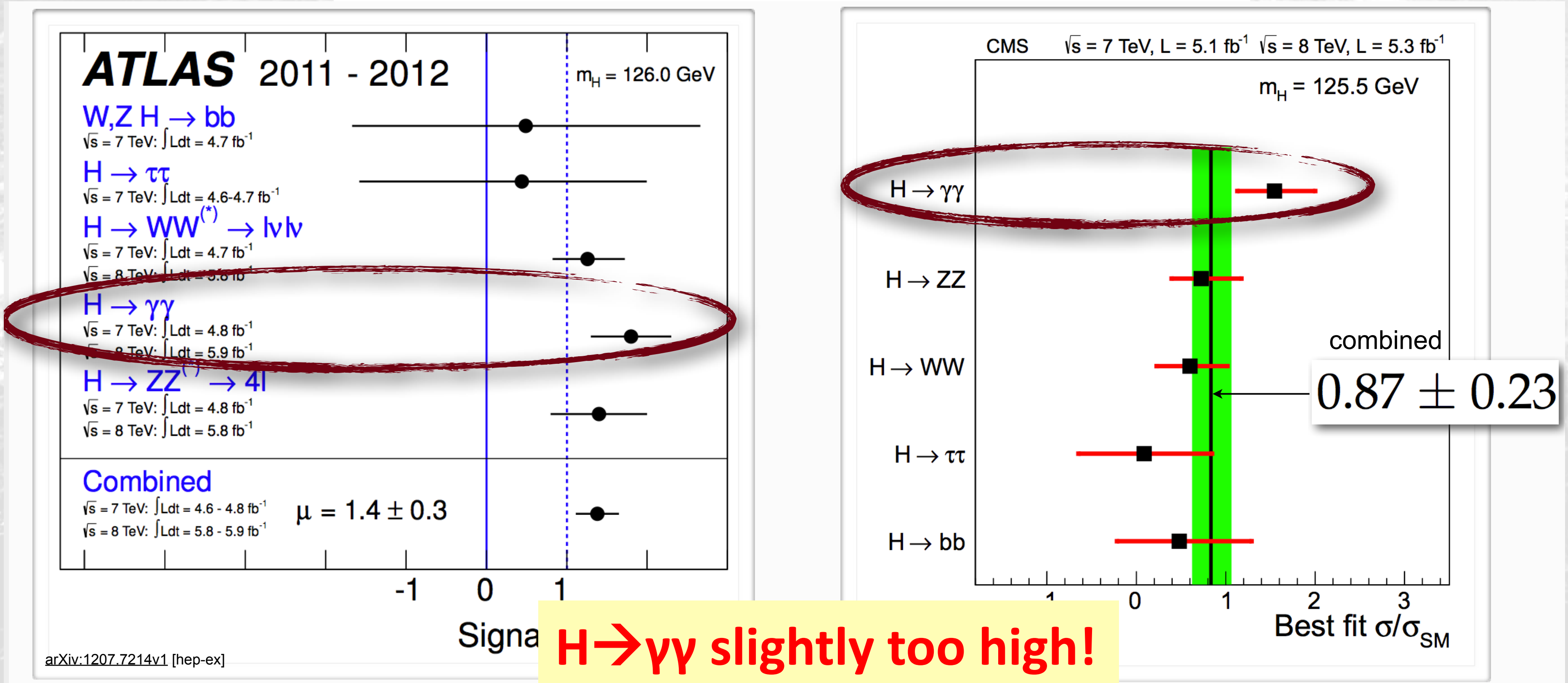
$125.3 \pm 0.4\,(\text{stat.}) \pm 0.5\,(\text{syst.})$ GeV



Higgs properties

- Current results show intriguing features (weak!)

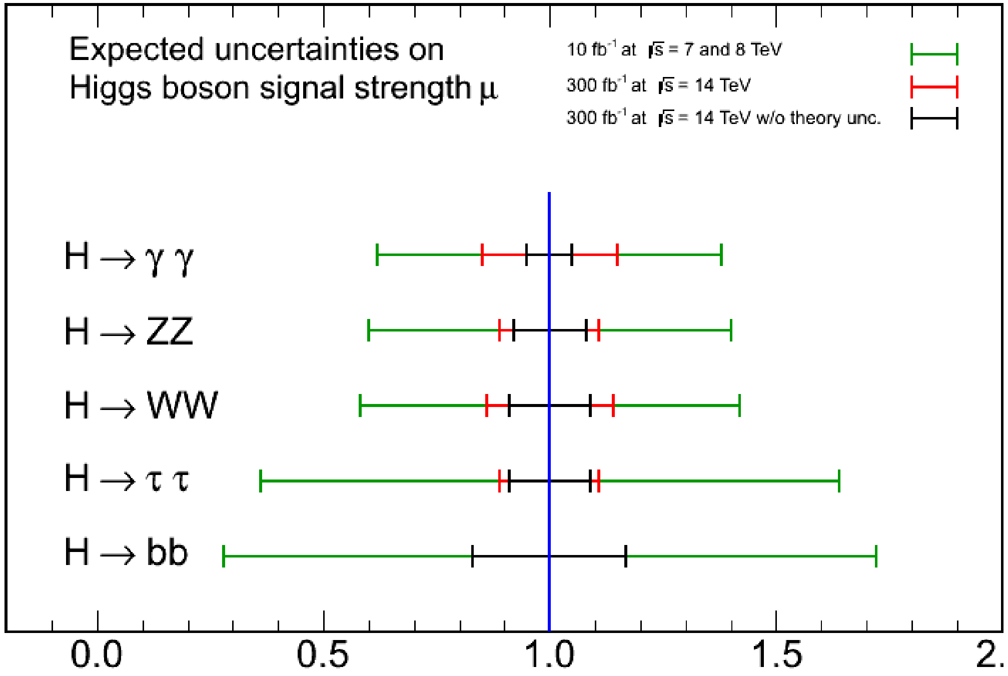
ATLAS:	$R_{\gamma\gamma} = 1.90 \pm 0.5\,,$	$R_{ZZ} = 1.3 \pm 0.6\,,$
CMS:	$R_{\gamma\gamma} = 1.56 \pm 0.43\,,$	$R_{ZZ} = 0.7 \pm 0.5\,,$
ATLAS⊕CMS:	$R_{\gamma\gamma} = 1.71 \pm 0.33\,,$	$R_{ZZ} = 0.95 \pm 0.4\,.$

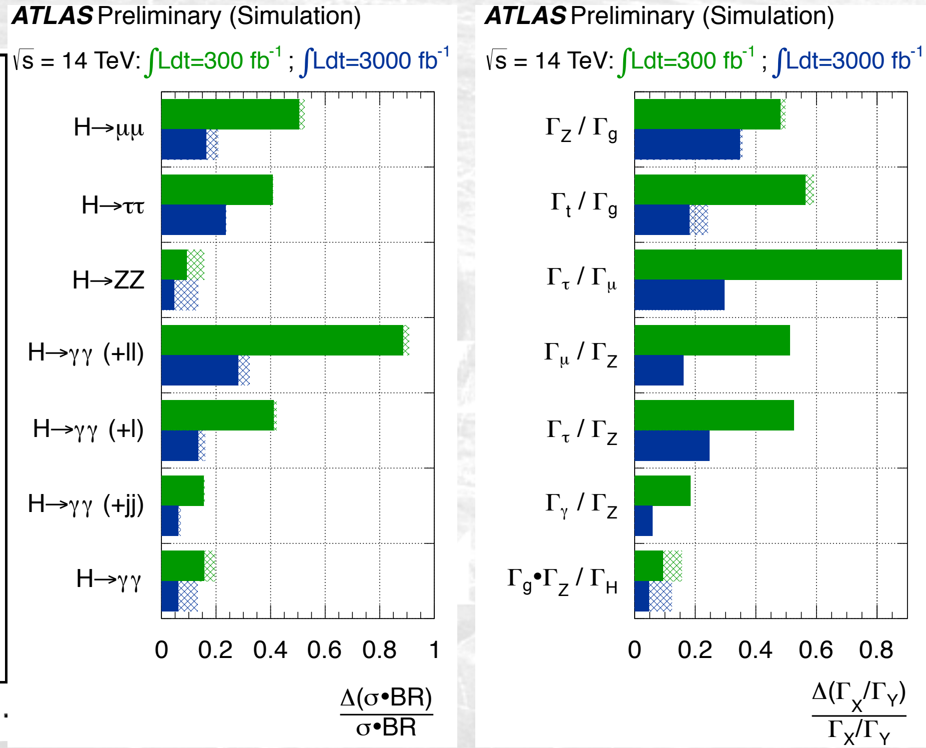


H→γγ slightly too high!

Higgs properties

- Projection (very preliminary) for branching ratios

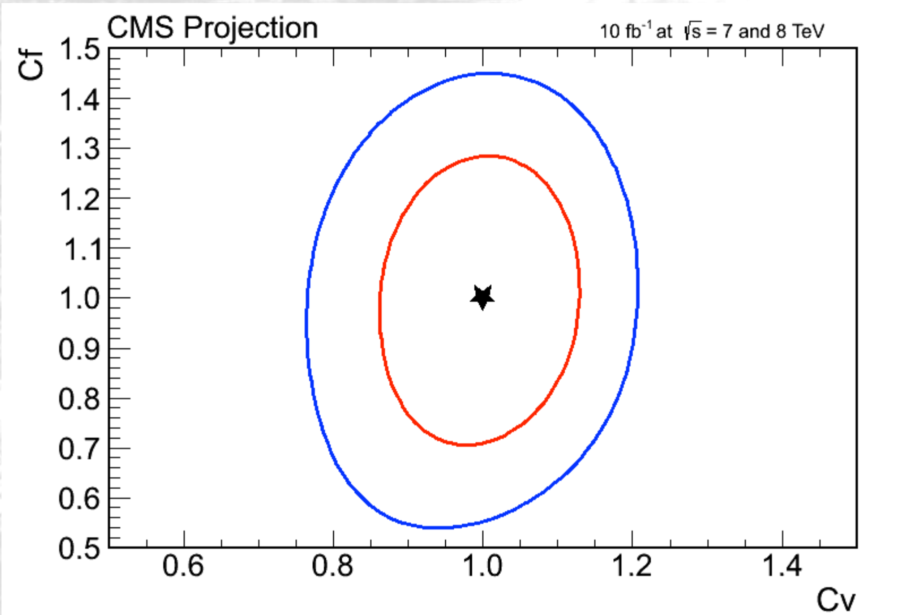


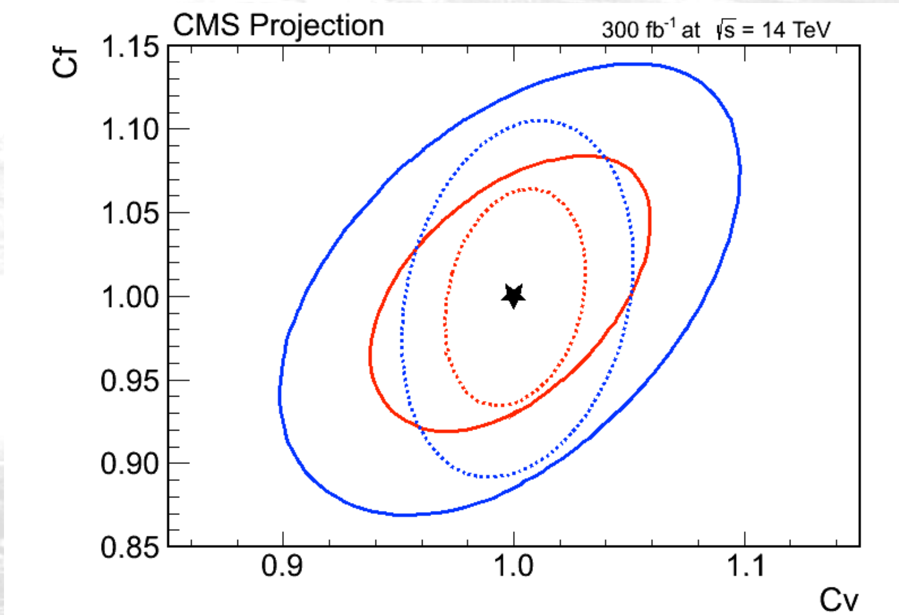


- Expect 5-10% precision achievable with 300/fb at 14 TeV

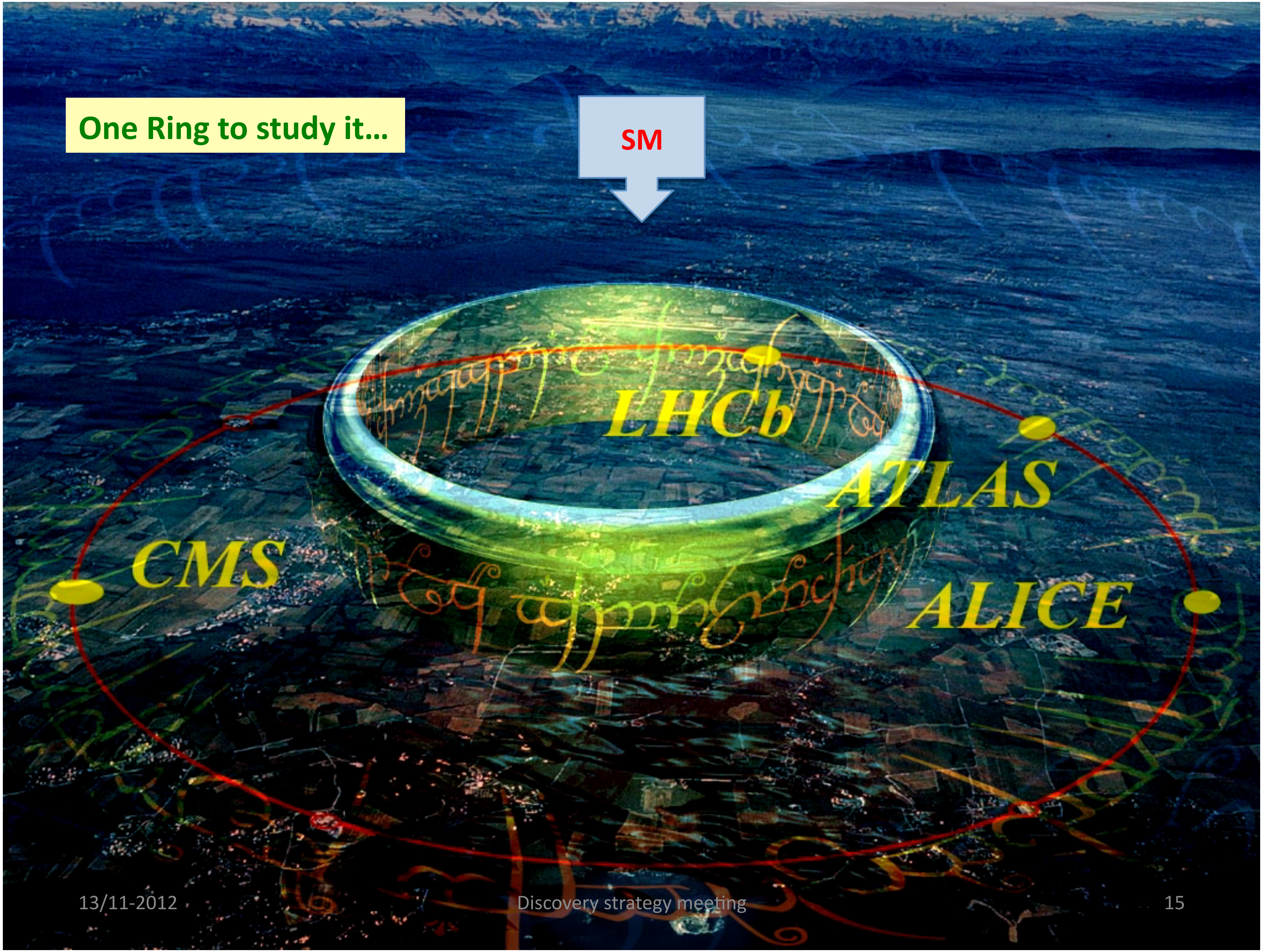
Anomalous Higgs couplings

- Compare fermionic operators versus bosonic





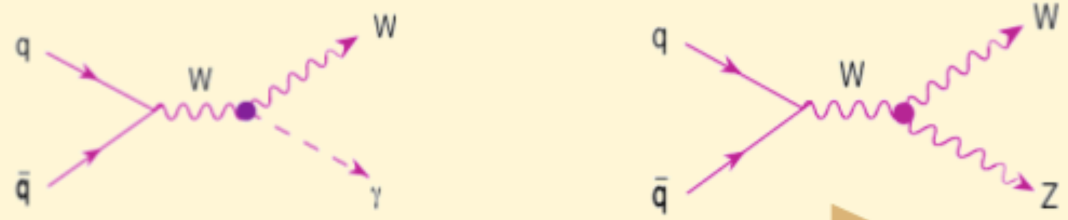
- Again 5-10% is expected with 300/fb at 14 TeV


One Ring to study it…
SM
LHCb
ATLAS
CMS
ALICE

Diboson Studies

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



LHC options

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

Broadly speaking, the sensitivity to new physics through TGCs extends beyond **10 TeV.**

Unitarity restoration

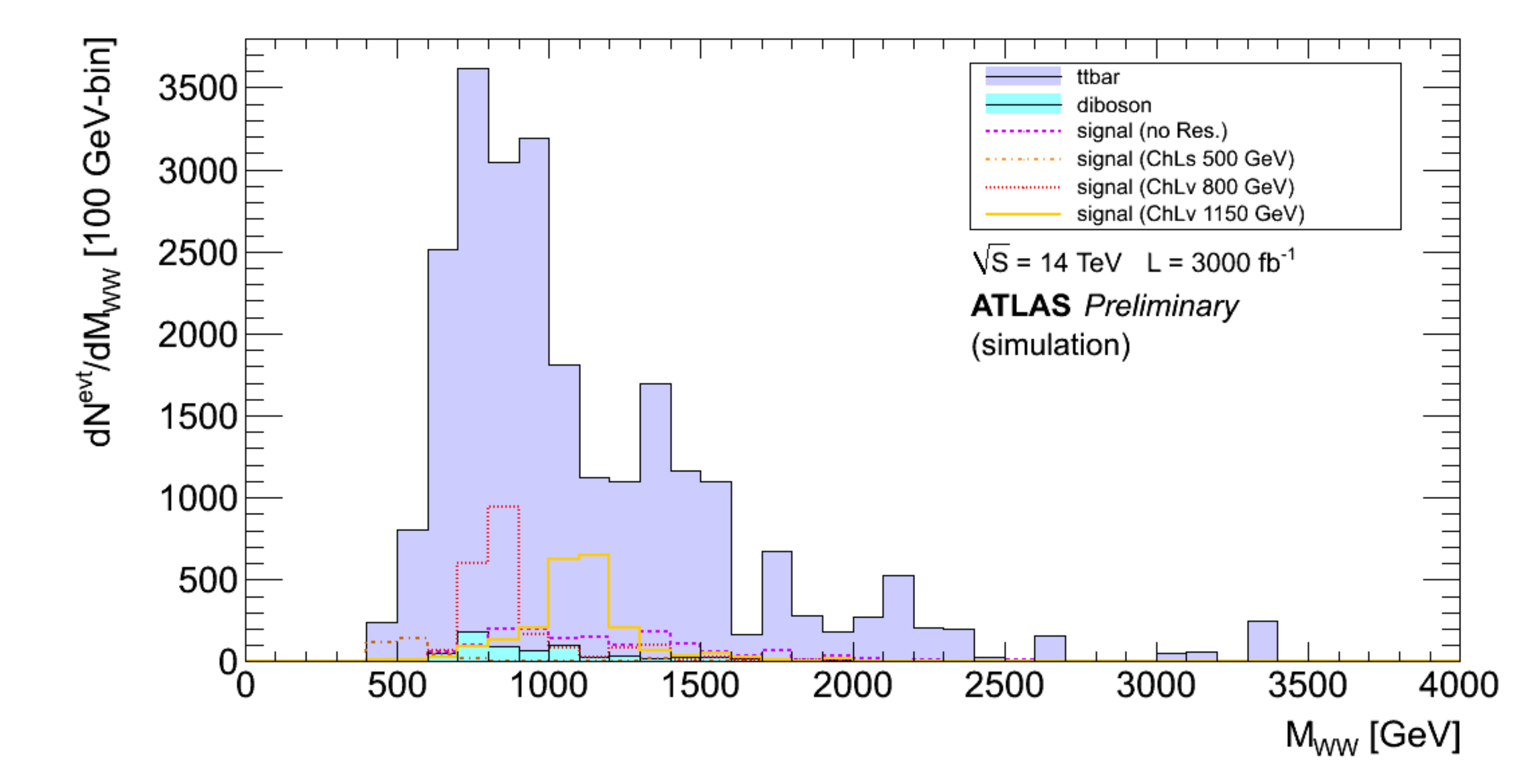
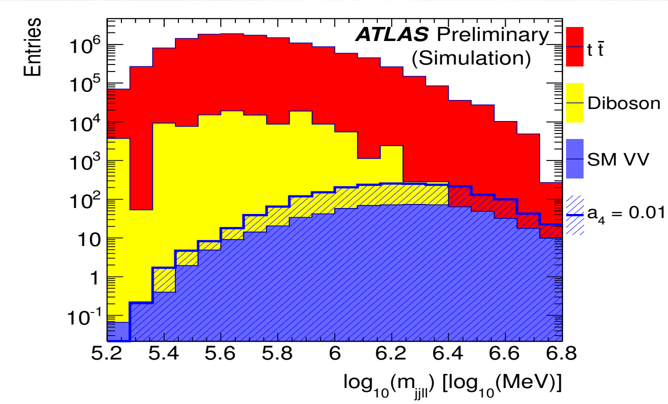


Table 2: Summary of sensitivity to various resonance hypotheses in the semi-leptonic WW channel.

model	baseline	500 GeV scalar	800 GeV vector	1150 GeVvector
(a_4, a_5)	(0, 0)	(0.01, 0.009)	(0.009, −0.007)	(0.004, −0.004)
S/B	(3.3 ± 0.3)%	(0.7 ± 0.1)%	(4.9 ± 0.3)%	(5.8 ± 0.3)%
$S/\sqrt{B}$ ($L = 300\text{fb}^{-1}$)	2.3 ± 0.3	0.6 ± 0.1	3.3 ± 0.4	3.9 ± 0.4
$S/\sqrt{B}$ ($L = 3000\,\text{fb}^{-1}$)	7.2 ± 0.1	1.6 ± 0.1	10.4 ± 0.7	12.4 ± 0.7

Diboson Studies –VBS



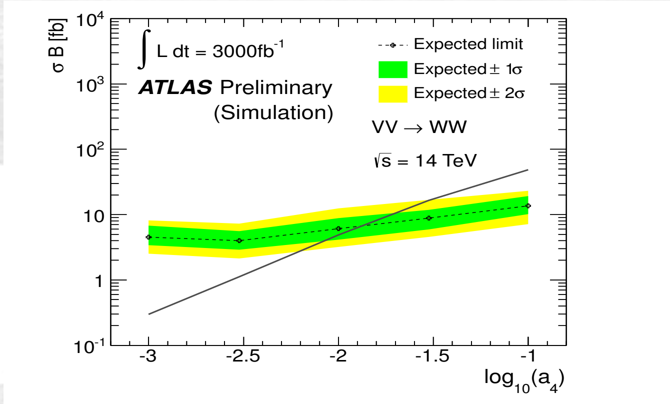


Figure 3: The reconstructed 4-body mass spectrum using the two leading leptons and jets for WW scattering in the $pp \to WW + 2j \to e\nu\mu\nu + 2j$ channel, showing backgrounds and signal for a value of $a_4 = 0.01$ (left), and the limit that can be set on the a_4 parameter (right) using the experimental σB limit (band) and the predicted cross section as a function of a_4 (solid line) for this channel.

Table 1: Summary of expected upper limits for a_4 at the 95% confidence level using the $pp \to WW + 2j \to e\nu\mu\nu + 2j$ search at $\sqrt{s} = 14$ TeV in the absence of a signal.

model	300 fb^{-1}	1000 fb^{-1}	3000 fb^{-1}
a_4	0.066	0.025	0.016

Diboson Studies

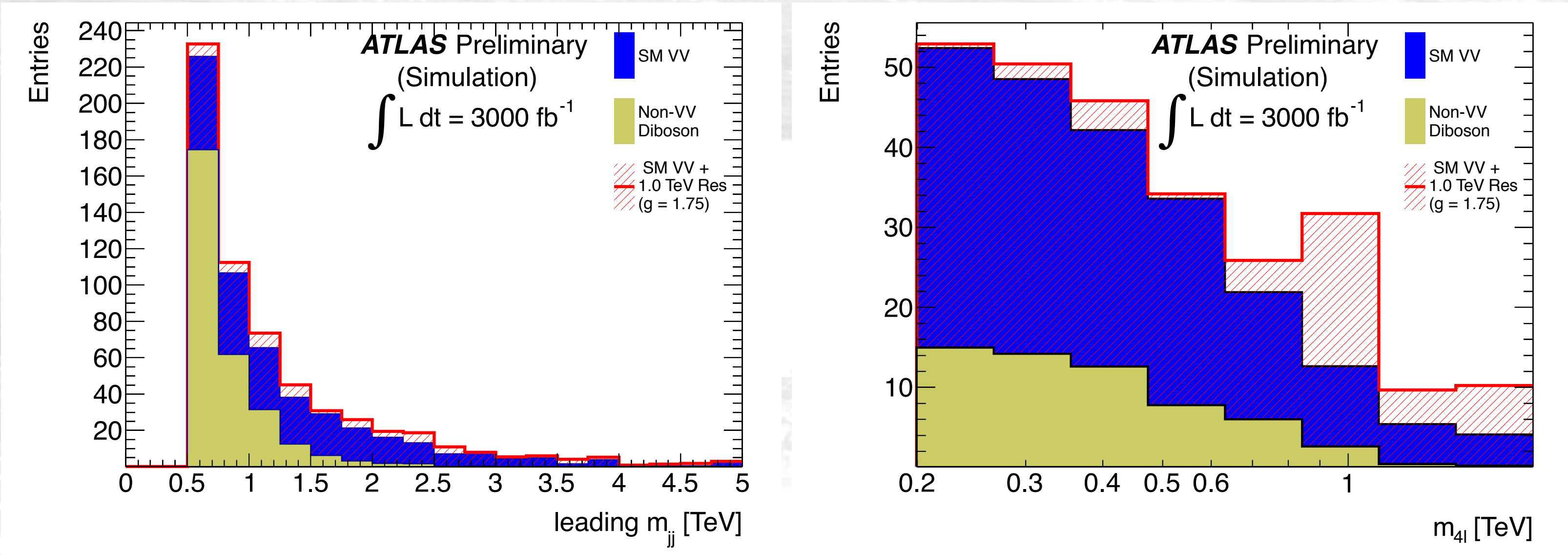
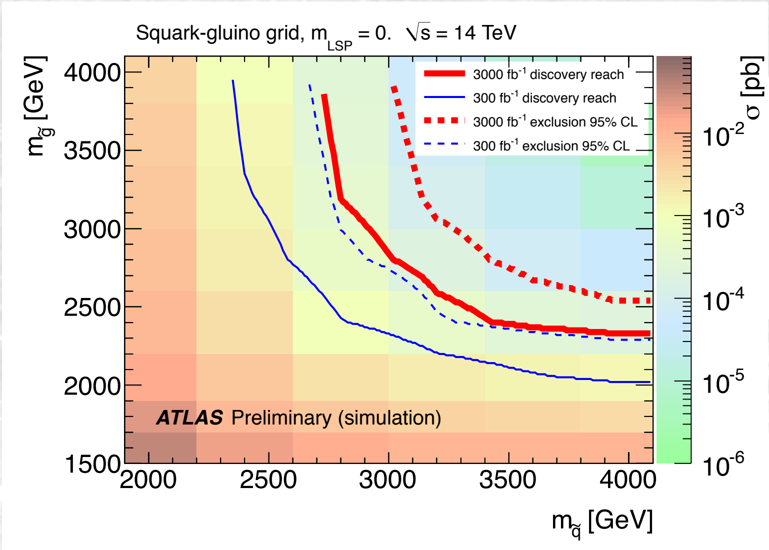


Figure 7.86: The leading jet-jet invariant mass (m_{jj}) distribution for simulated events in the $pp \to ZZ + 2j \to \ell\ell\ell\ell + 2j$ channel (left), and the reconstructed 4-lepton mass ($m_{4\ell}$) spectrum for this channel after requiring $m_{jj} > 1$ TeV (right). The VBS events are generated using WHIZARD without and with a ZZ resonance mass of 1 TeV and coupling $g = 1.75$, and the non-VBS diboson background is generated using MADGRAPH [102].

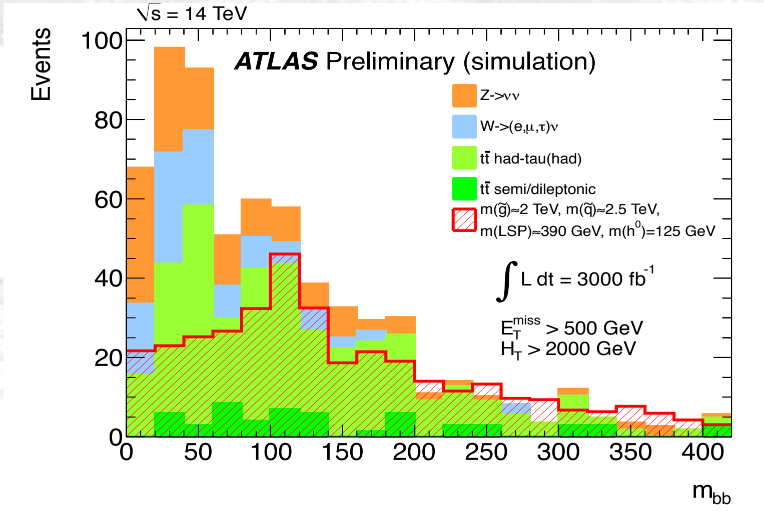
model	$300\,\text{fb}^{-1}$	$3000\,\text{fb}^{-1}$
$m_{\text{resonance}} = 500$ GeV, $g = 1.0$	2.4σ	7.5σ
$m_{\text{resonance}} = 1$ TeV, $g = 1.75$	1.7σ	5.5σ
$m_{\text{resonance}} = 1$ TeV, $g = 2.5$	3.0σ	9.4σ


One Ring to study them…
One Ring to Find Them ???
LHCb
ATLAS
CMS
ALICE
BSM
One Ring to Rule Them Out ???

Origin of Electroweak Symmetry breaking
SUSY



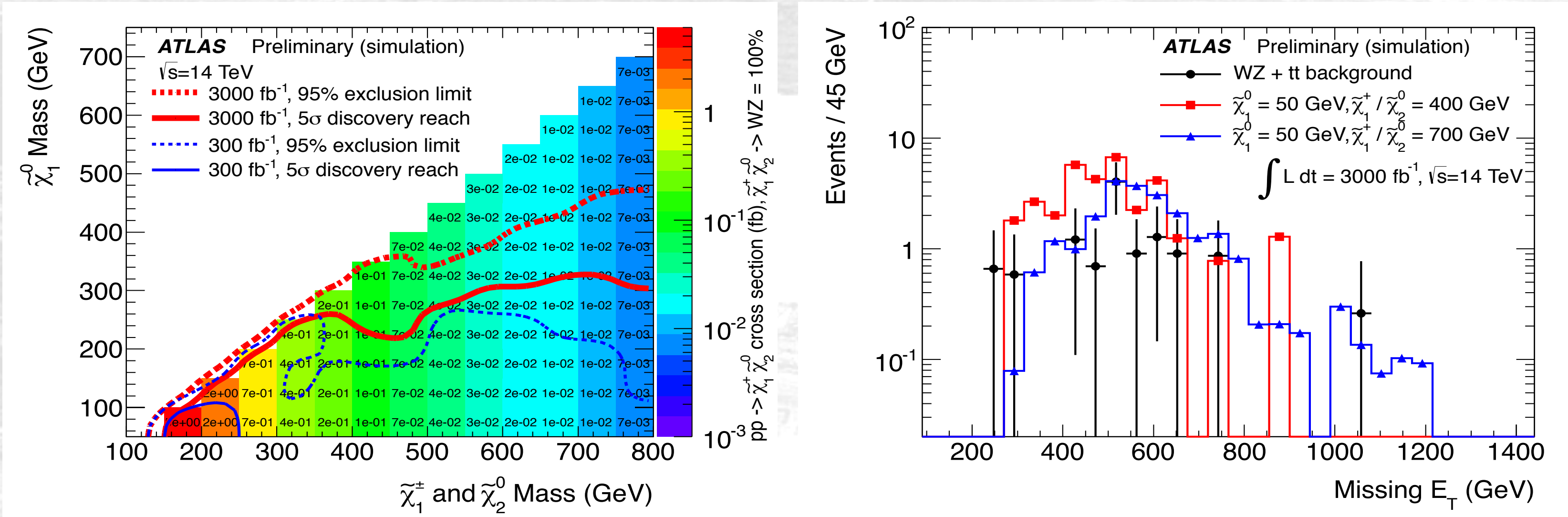
(a)



(b)

Figure 5: (a) The 95% CL exclusion limits (solid lines) and 5σ discovery reach (dashed lines) in a simplified squark–gluino model with massless neutralino with $300\,\text{fb}^{-1}$ (blue lines) and $3000\,\text{fb}^{-1}$ (red lines). The colour scale shows the $\sqrt{s} = 14\,\text{TeV}$ NLO production cross section calculated by `Prospino 2.1` [18]. (b) The m_{bb} invariant mass distribution for a benchmark SUSY model compared to the SM background processes for $3000\,\text{fb}^{-1}$ of integrated luminosity.

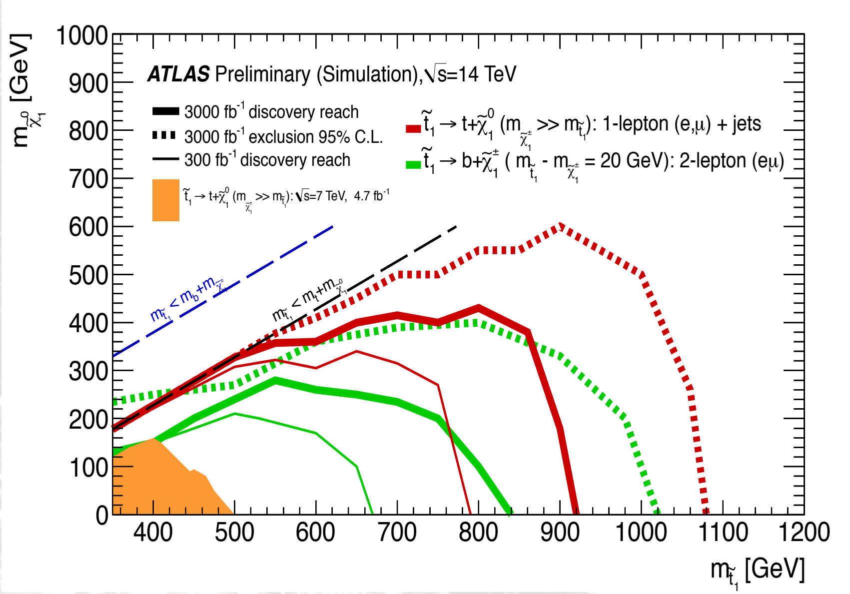
Origin of Electroweak Symmetry breaking
SUSY



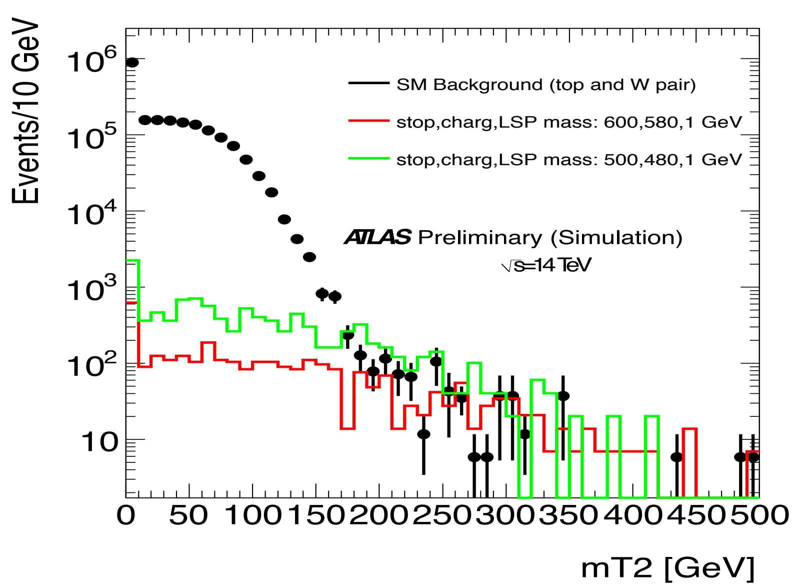
(a) (b)

Figure 7: (a) The 95% CL exclusion limits (dashed lines) and 5σ discovery reach (solid lines) for charginos and neutralinos undergoing $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow W^{(*)}\tilde{\chi}_1^0 Z^{(*)}\tilde{\chi}_1^0$ decays with BR=100%. The case of 300 fb^{-1} and 3000 fb^{-1} are reported. (b) The missing transverse momentum distribution in three-lepton events surviving the BDT-based selection.

Origin of Electroweak Symmetry breaking SUSY



(a)



(b)

Figure 6: (a) The 95% CL exclusion limits for $3000\,\mathrm{fb}^{-1}$ (dashed) and 5σ discovery reach (solid) for $300\,\mathrm{fb}^{-1}$ and $3000\,\mathrm{fb}^{-1}$ in the $\tilde{t}, \tilde{\chi}_1^0$ mass plane assuming the $\tilde{t} \to t + \tilde{\chi}_1^0$ (red) or the $\tilde{t} \to b + \tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \to W + \tilde{\chi}_1^0$ (green) decay mode. (b) The m_{T2} distribution for two-lepton channel for SM background and 2 benchmark SUSY scenarios.

Origin of Electroweak Symmetry breaking
SUSY

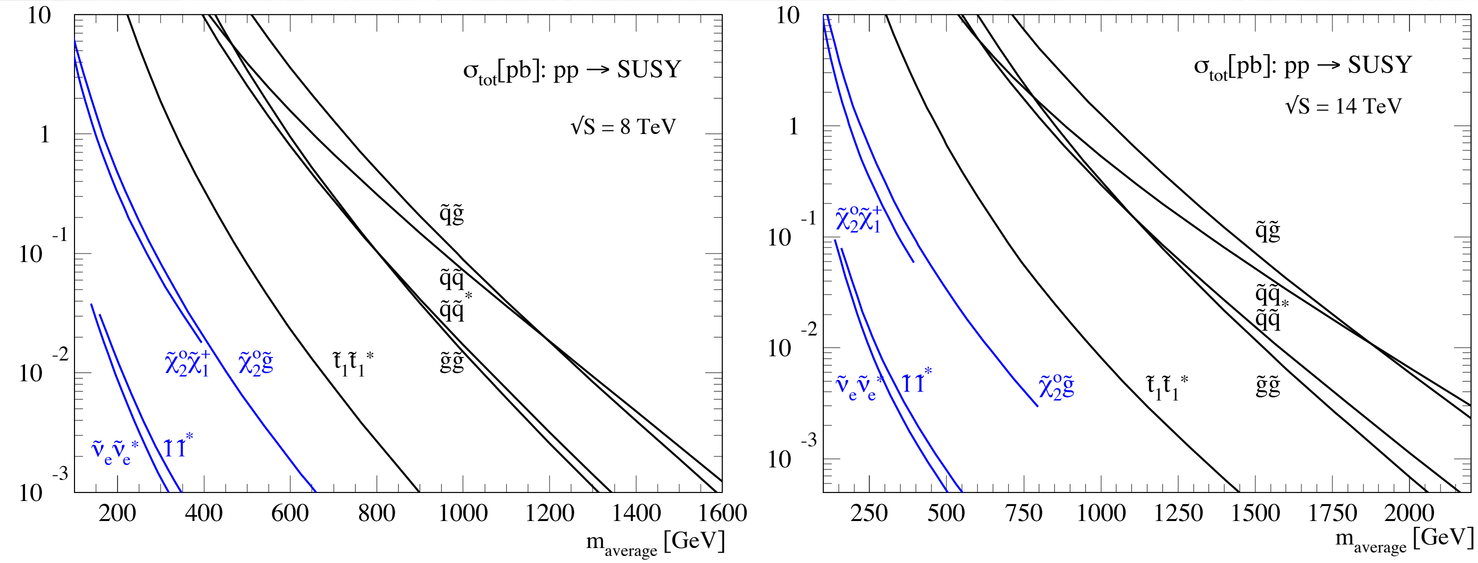
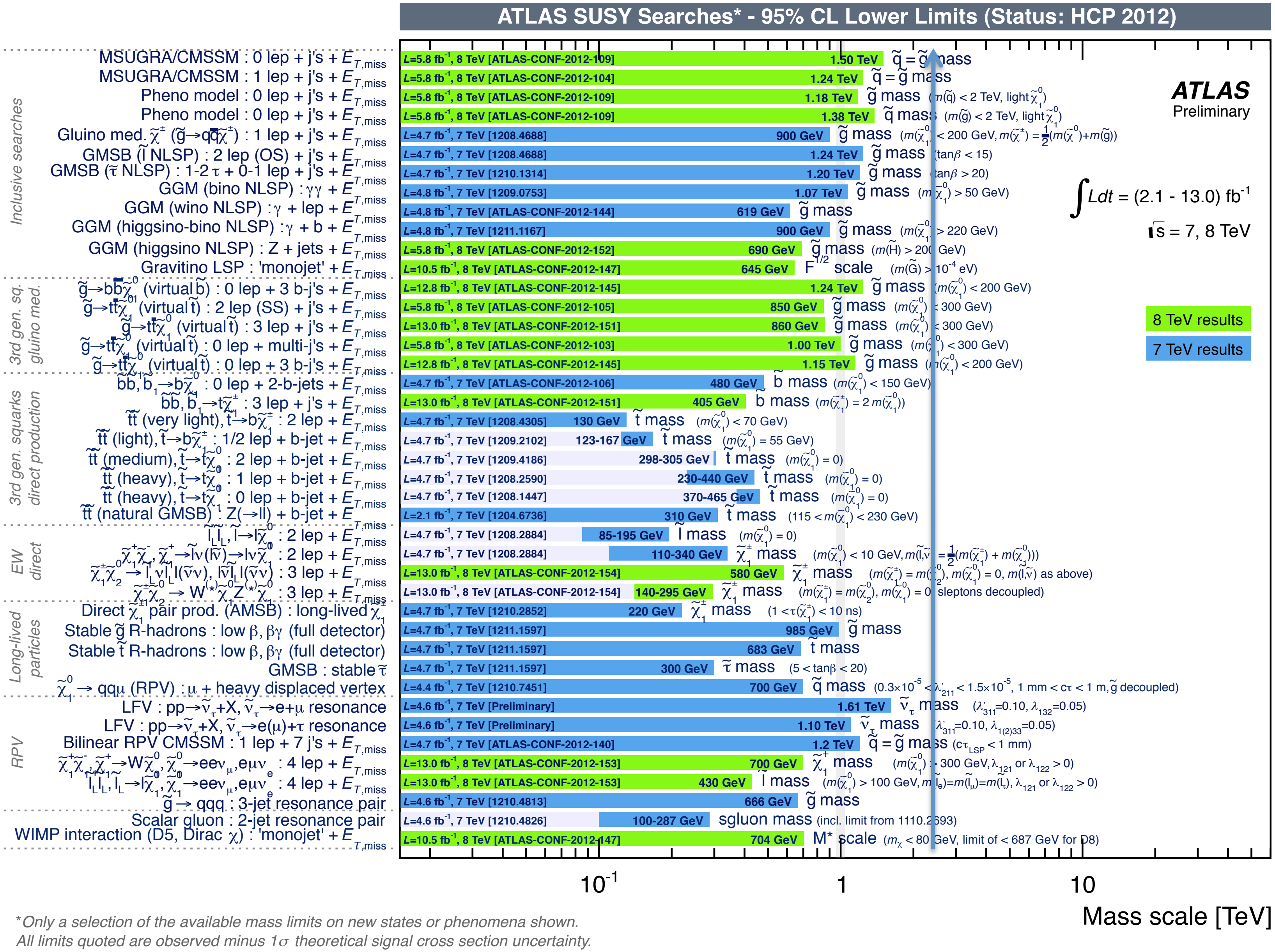
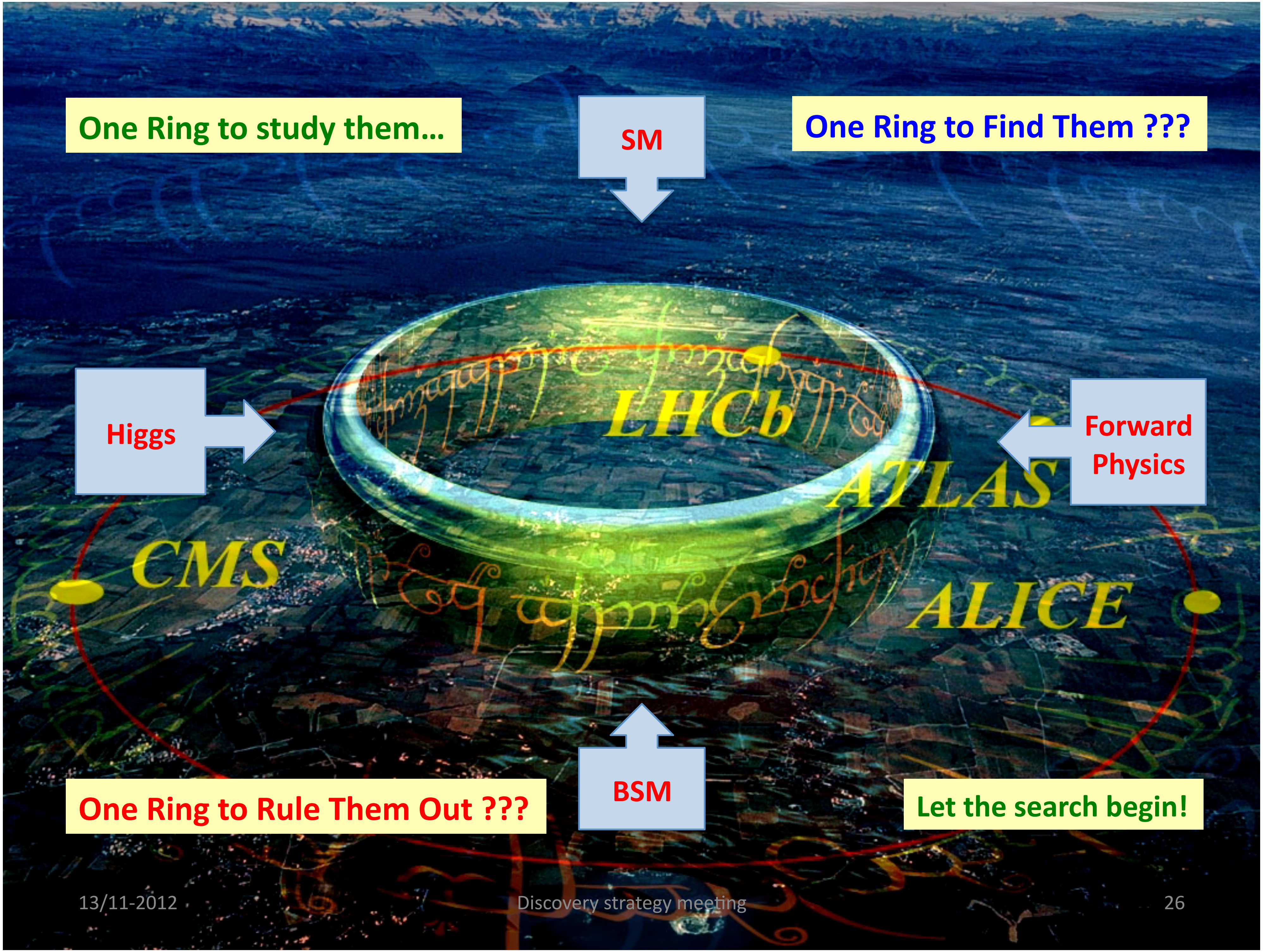


Fig. 1: SUSY production cross sections at the LHC with $\sqrt{s} = 8$ TeV (left) and 14 TeV (right). The model parameters correspond to the CMSSM line 10.4, defined in ref. [1].

Approximately a factor 2-3 improvement – depending on production mode g<->q


ATLAS SUSY Searches* - 95% CL Lower Limits (Status: HCP 2012)
ATLAS
Preliminary
∫Ldt = (2.1 - 13.0) fb⁻¹
√s = 7, 8 TeV
8 TeV results
7 TeV results
Inclusive searches
3rd gen. sq. gluino med.
3rd gen. squarks direct production
EW direct
Long-lived particles
RPV
MSUGRA/CMSSM : 0 lep + j's + E_T,miss
MSUGRA/CMSSM : 1 lep + j's + E_T,miss
Pheno model : 0 lep + j's + E_T,miss
Pheno model : 0 lep + j's + E_T,miss
GMSB (l̃ NLSP) : 2 lep (OS) + j's + E_T,miss
GMSB (τ̃ NLSP) : 1-2 τ + 0-1 lep + j's + E_T,miss
GGM (bino NLSP) : γγ + E_T,miss
GGM (wino NLSP) : γ + lep + E_T,miss
GGM (higgsino-bino NLSP) : γ + b + E_T,miss
GGM (higgsino NLSP) : Z + jets + E_T,miss
Gravitino LSP : 'monojet' + E_T,miss
Direct χ̃±₁ pair prod. (AMSB) : long-lived χ̃±₁
Stable g̃ R-hadrons : low β, βγ (full detector)
Stable t̃ R-hadrons : low β, βγ (full detector)
GMSB : stable τ̃
LFV : pp→ν̃τ+X, ν̃τ→e+μ resonance
LFV : pp→ν̃τ+X, ν̃τ→e(μ)+τ resonance
Bilinear RPV CMSSM : 1 lep + 7 j's + E_T,miss
g̃ → qqq : 3-jet resonance pair
Scalar gluon : 2-jet resonance pair
WIMP interaction (D5, Dirac χ) : 'monojet' + E_T,miss
L=5.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-109] 1.50 TeV q̃ = g̃ mass
L=5.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-104] 1.24 TeV q̃ = g̃ mass
L=5.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-109] 1.18 TeV g̃ mass
L=5.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-109] 1.38 TeV q̃ mass
L=4.7 fb⁻¹, 7 TeV [1208.4688] 900 GeV g̃ mass
L=4.7 fb⁻¹, 7 TeV [1208.4688] 1.24 TeV g̃ mass
L=4.7 fb⁻¹, 7 TeV [1210.1314] 1.20 TeV g̃ mass
L=4.8 fb⁻¹, 7 TeV [1209.0753] 1.07 TeV g̃ mass
L=4.8 fb⁻¹, 7 TeV [ATLAS-CONF-2012-144] 619 GeV g̃ mass
L=4.8 fb⁻¹, 7 TeV [1211.1167] 900 GeV g̃ mass
L=5.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-152] 690 GeV g̃ mass
L=10.5 fb⁻¹, 8 TeV [ATLAS-CONF-2012-147] 645 GeV F^1/2 scale
L=12.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-145] 1.24 TeV g̃ mass
L=5.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-105] 850 GeV g̃ mass
L=13.0 fb⁻¹, 8 TeV [ATLAS-CONF-2012-151] 860 GeV g̃ mass
L=5.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-103] 1.00 TeV g̃ mass
L=12.8 fb⁻¹, 8 TeV [ATLAS-CONF-2012-145] 1.15 TeV g̃ mass
L=4.7 fb⁻¹, 7 TeV [ATLAS-CONF-2012-106] 480 GeV b̃ mass
L=13.0 fb⁻¹, 8 TeV [ATLAS-CONF-2012-151] 405 GeV b̃ mass
L=4.7 fb⁻¹, 7 TeV [1208.4305] 130 GeV t̃ mass
L=4.7 fb⁻¹, 7 TeV [1209.2102] 123-167 GeV t̃ mass
L=4.7 fb⁻¹, 7 TeV [1209.4186] 298-305 GeV t̃ mass
L=4.7 fb⁻¹, 7 TeV [1208.2590] 230-440 GeV t̃ mass
L=4.7 fb⁻¹, 7 TeV [1208.1447] 370-465 GeV t̃ mass
L=2.1 fb⁻¹, 7 TeV [1204.6736] 310 GeV t̃ mass
L=4.7 fb⁻¹, 7 TeV [1208.2884] 85-195 GeV l̃ mass
L=4.7 fb⁻¹, 7 TeV [1208.2884] 110-340 GeV χ̃±₁ mass
L=13.0 fb⁻¹, 8 TeV [ATLAS-CONF-2012-154] 580 GeV χ̃±₁ mass
L=13.0 fb⁻¹, 8 TeV [ATLAS-CONF-2012-154] 140-295 GeV χ̃±₁ mass
L=4.7 fb⁻¹, 7 TeV [1210.2852] 220 GeV χ̃±₁ mass
L=4.7 fb⁻¹, 7 TeV [1211.1597] 985 GeV g̃ mass
L=4.7 fb⁻¹, 7 TeV [1211.1597] 683 GeV t̃ mass
L=4.7 fb⁻¹, 7 TeV [1211.1597] 300 GeV τ̃ mass
L=4.4 fb⁻¹, 7 TeV [1210.7451] 700 GeV q̃ mass
L=4.6 fb⁻¹, 7 TeV [Preliminary] 1.61 TeV ν̃τ mass
L=4.6 fb⁻¹, 7 TeV [Preliminary] 1.10 TeV ν̃τ mass
L=4.7 fb⁻¹, 7 TeV [ATLAS-CONF-2012-140] 1.2 TeV q̃ = g̃ mass
L=13.0 fb⁻¹, 8 TeV [ATLAS-CONF-2012-153] 700 GeV χ̃±₁ mass
L=13.0 fb⁻¹, 8 TeV [ATLAS-CONF-2012-153] 430 GeV l̃ mass
L=4.6 fb⁻¹, 7 TeV [1210.4813] 666 GeV g̃ mass
L=4.6 fb⁻¹, 7 TeV [1210.4826] 100-287 GeV sgluon mass (incl. limit from 1110.2693)
L=10.5 fb⁻¹, 8 TeV [ATLAS-CONF-2012-147] 704 GeV M* scale
10⁻¹
1
10
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.


One Ring to study them…
SM
One Ring to Find Them ???
Higgs
LHCb
Forward Physics
ATLAS
CMS
ALICE
BSM
One Ring to Rule Them Out ???
Let the search begin!