LHC physics prospect

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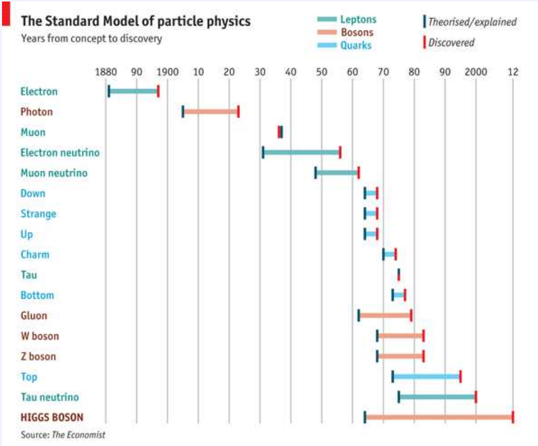
Gotcha!

The longest endeavour in the Standard Model ended in July

The 48 year itch : from idea to observation

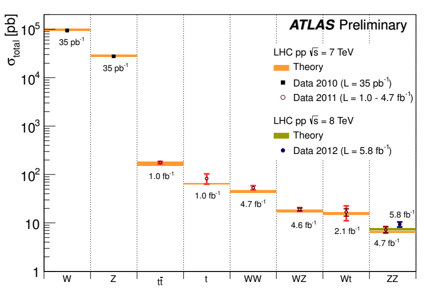


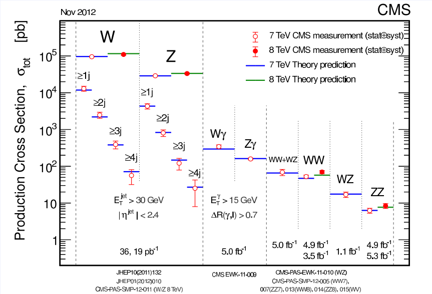
- Timelines showing the idea of a particle to its discovery

Chronicle towards the discovery at LHC

Conquest of known particles

Re-discovery of the Standard Model

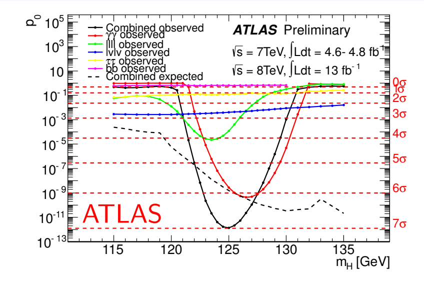




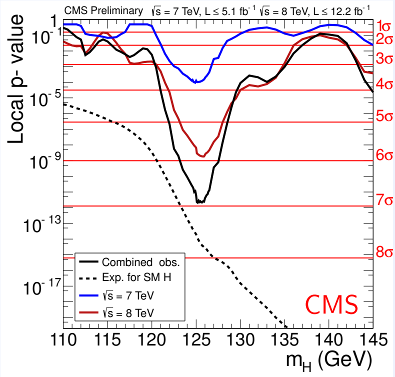
- Starting from weak gauge boson production measurements
- measurement of top production
- measurement of di-boson productions

which paved the way for ...

Discovery of a new particle



p-value : probability of observing such a result if no signal was there



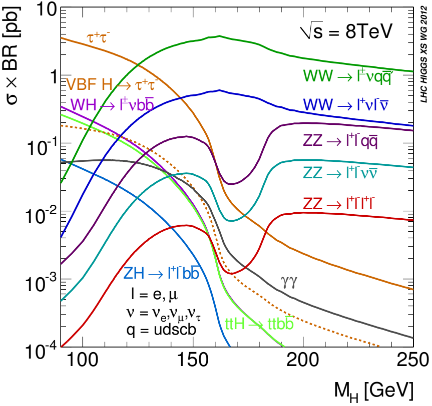
- Status of LHC experiments
- What is the next?
    - LHC upgrades
    - LHC physics prospects
- Summary

Standard Model Higgs - a reminder

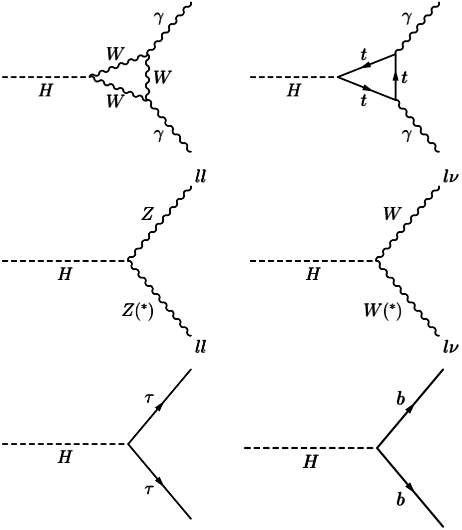
Branching ratios at 125 GeV

Decay mode	BR	Decay mode	BR
bb	57.7%	ZZ	2.6%
WW	21.5%	$\gamma\gamma$	0.23%
$\tau\tau$	6.3%		

$\sigma\times$ BR for each final state

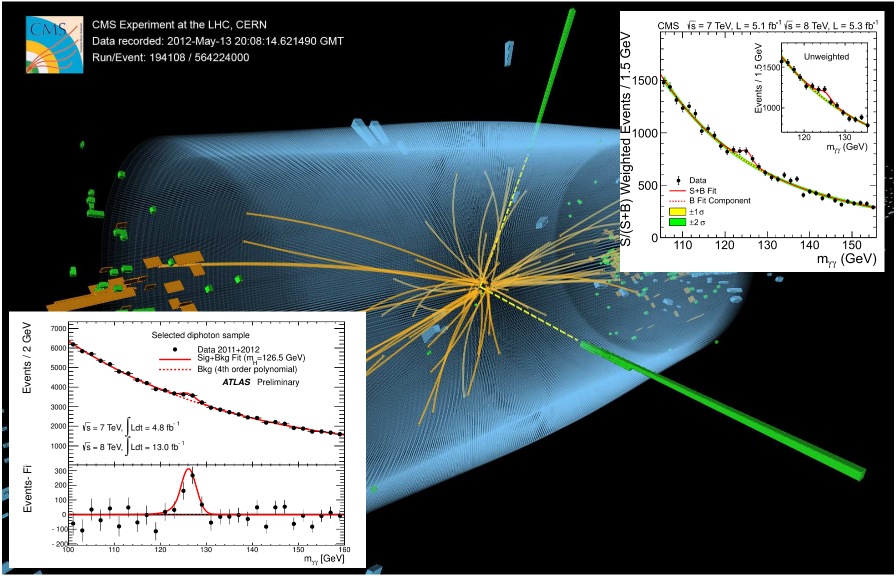


Important decay modes at 125 GeV



Higgs-like particle

$H \to \gamma\gamma$ candidate



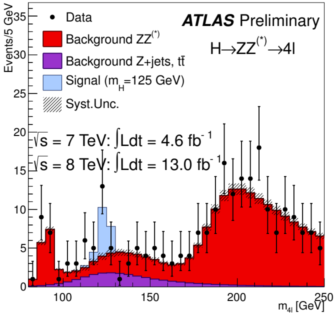
Higgs-like particle

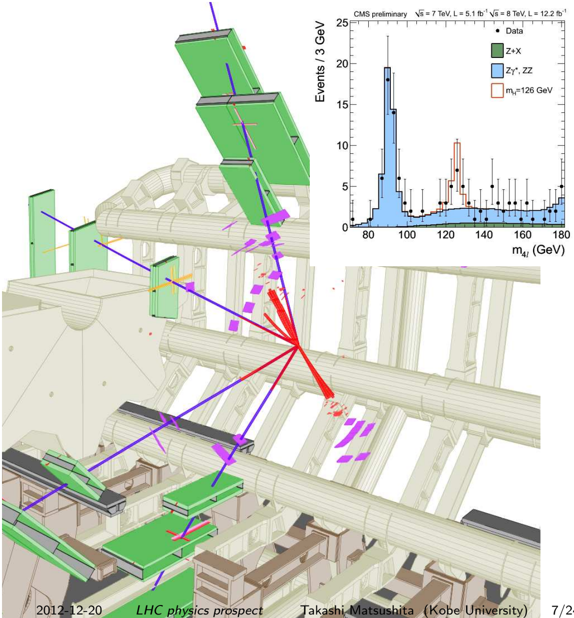
$H \to ZZ^* \to llll$ candidate

Run Number: 189280,
Event Number: 143576946
Date: 2011-09-14, 11:37:11 CET

EtCut>0.3 GeV
PtCut>3.0 GeV
Vertex Cuts:
Z direction <1cm
Rphi <1cm

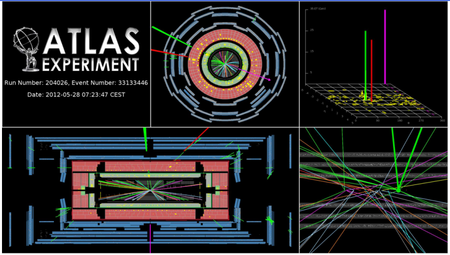
Muon: blue
Cells:Tiles, EMC





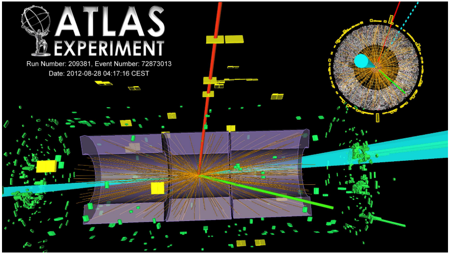
Higgs-like particle

candidates of $H \to WW^* \to l\nu l\nu$, $H \to \tau_{lep}\tau_{lep}$, $WH \to (\mu\nu)bb$

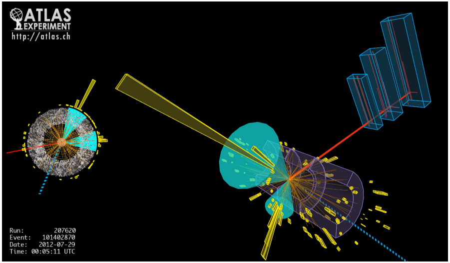


$H \to WW^* \to e\nu\mu\nu$

- Candidate events for more challenging decay modes

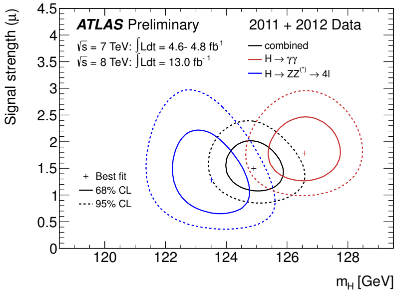


$H \to \tau_{lep}\tau_{lep}$



$WH \to \mu\nu bb$

Is this particle the Standard Model Higgs?



ATLAS

$$m_X = 125.2 \pm 0.3\ (\text{stat.}) \pm 0.6\ (\text{syst.})\ \text{GeV}$$

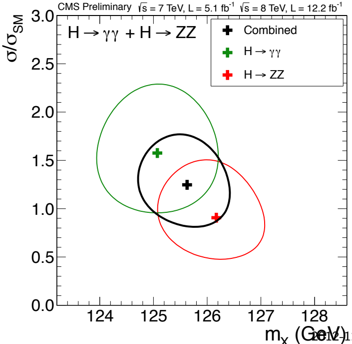
$$\hat{\mu} \simeq 1.5$$

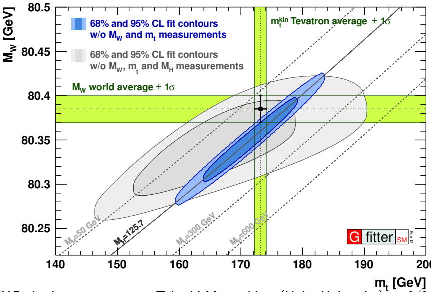
compatibility of the $m_{\gamma\gamma}$ and m_{4l} is estimated to be $\sim 2.7\,\sigma$

CMS

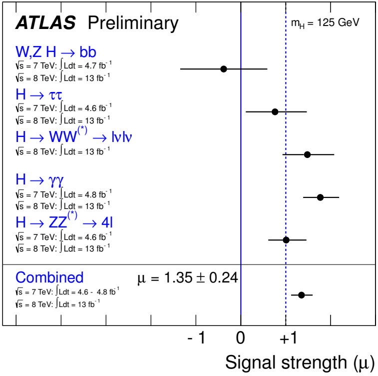
$$m_X = 125.8 \pm 0.4\ (\text{stat.}) \pm 0.4\ (\text{syst.})\ \text{GeV}$$

$$\hat{\mu} \simeq 1.25$$

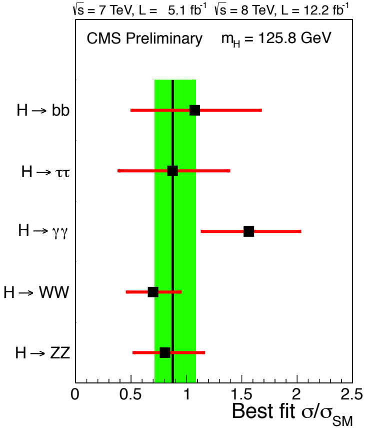




Is this particle the Standard Model Higgs?



$$\hat{\mu} = 1.35 \pm 0.24$$

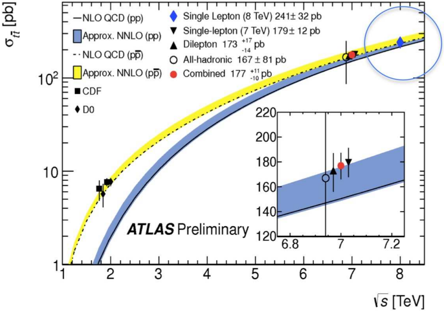


$$\hat{\mu} = 0.88 \pm 0.21$$

- Overall signal strength consistent with the SM Higgs
- Performed spin-parity analysis. Preference of 0^+ hypothesis.
- *Need more data to reduce uncertainties*

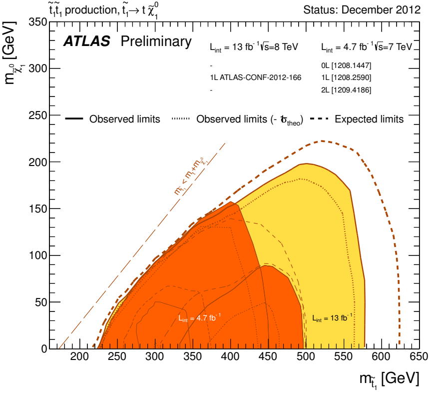
top and search with top

- top-pair cross section measurements at 7 and 8 TeV



- Good agreement with the predictions
- $m_{\text{top}} = 173.2 \pm 0.5$ (stat) ± 1.3 (syst) GeV

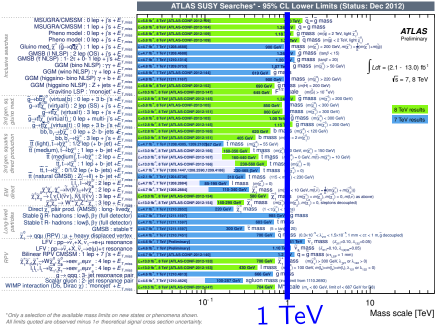
- Search for SUSY with top
  - $\tilde{t} \longrightarrow t\chi$



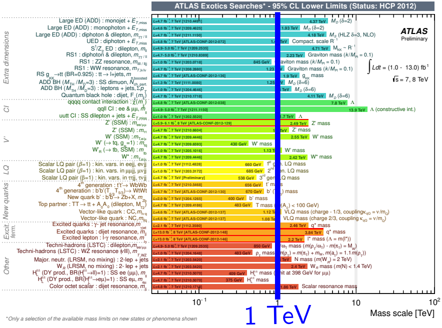
- Mass reach improved with 8 TeV data, up to $\sim$ 580 GeV

New physics search

SUSY



non-SUSY

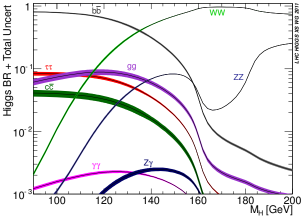


- Numerous searches have been performed but no direct evidence of new physics (yet)

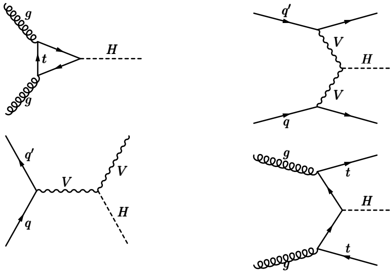
What is the next?

"In the absence of any direct evidence of new physics, the Higgs will be one of the best source of information about possible new physics"

- Natural question is...
- Is this the Standard Model Higgs or a Higgs beyond the SM?
  - All couplings as expected?
  - All production modes as expected?

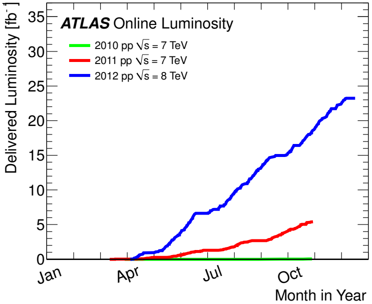


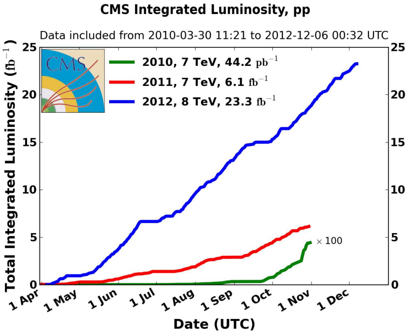
- But for what precision?
  - SUSY, composite Higgs, top partners etc. will give a few percent deviation from the Standard Model on Higgs couplings. Up to 5% in some models.

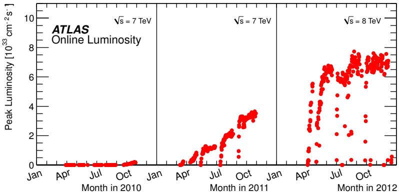


Large Hadron Collider: 2010-2012

successful years of initial physics runs







- The results shown so far used up to 12-13 fb^{-1} of 2012 data
- Expects update with full dataset, which will shrink uncertainties a bit
- For more precise measurements, we will need large statistics

What LHC can do for us?

LHC timeline

- LHC start-up
  - 7-8 TeV, 8×10^{33} cm^{-2}s^{-1}, $\mathcal{L} \sim 30$ fb^{-1}
- Go to design energy, nominal luminosity
  - 13-14 TeV, 1×10^{34} cm^{-2}s^{-1}, $\mathcal{L} \sim 100$ fb^{-1}
- LHC phase-I upgrade to full design luminosity
  - 14 TeV, 2×10^{34} cm^{-2}s^{-1}, $\mathcal{L} \sim 200$ fb^{-1}
- HL-LHC phase-II upgrade
  - 14 TeV, 5×10^{34} cm^{-2}s^{-1}, $\mathcal{L} \sim 3000$ fb^{-1} (luminosity levelled)

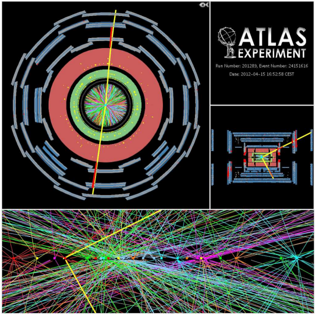
Physics programmes

- With LHC 7-8 TeV data until 2012 ($\sim$ 30 fb^{-1})
  - First characterisation of Higgs-like boson
    - $\sim$ 330 $\gamma\gamma$ candidates with 13 fb^{-1} at 8 TeV
    - $\sim$ 10 four-lepton candidates with 13 fb^{-1} at 8 TeV
- With LHC 13/14 TeV data until $\sim$ 2022 ($\sim$ 300 fb^{-1})
  - Measure Higgs-like boson properties
  - Search for new physics at higher mass scale
- With LHC 14 TeV data until $\sim$ 2032 ($\sim$ 3000 fb^{-1})
  - Measure Higgs-like couplings with ultimate precision
  - Study Vector boson scattering
  - Search for new physics in rare processes

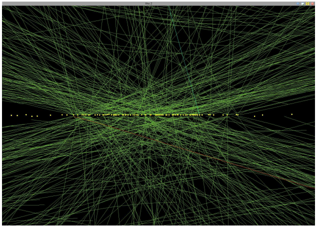
Experimental challenges at the upgraded LHC

- Need detectors and trigger with high performance from low to high energy scales in severe pile-up environments
- $\sim$ 50 collisions per beam crossing after the phase I upgrade
- $\sim$ 125 collisions per beam crossing after the phase II upgrade
- Upgrade of detectors are also planned (but not covered) for performing physics studies with the upgraded LHC

25 reconstructed vertices

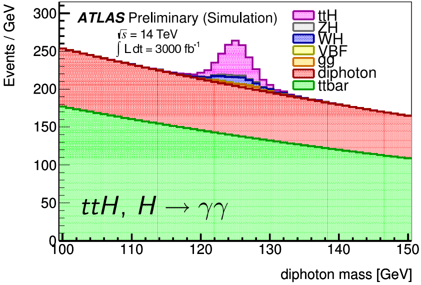


78 reconstructed vertices

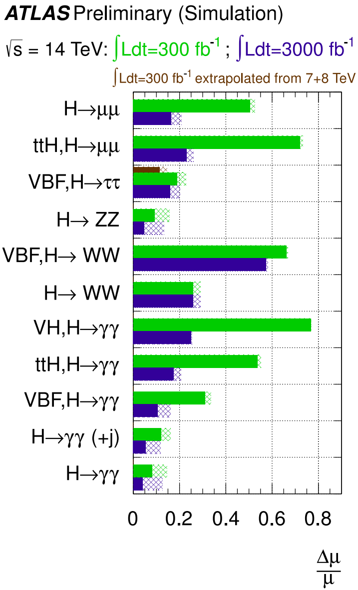


Expected uncertainties on $\hat{\mu}$

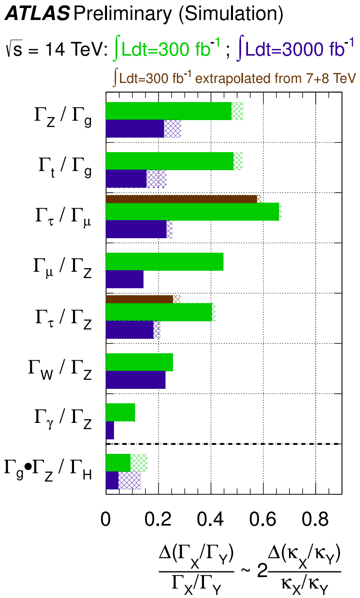
- MC study with fast-simulation
  - truth with smearing: best estimate of physics objects dependency on pile-up
  - μ up to 140, validated with full-simulation up to $\mu \sim 70$



- $\gamma\gamma$ and ZZ^* profit most from the high luminosity, down to $\sim 5\%$ experimental uncertainty



Expected uncertainties on Higgs couplings



- Cannot measure Higgs width - $\Gamma_H \sim 4.2$ MeV @ 125 GeV, but ratios of couplings

- ATLAS expectations on $\kappa_{V(F)}$, where $\kappa^2_{V(F)} \sim \Gamma_{V(F)} \sim \sigma_{V(F)}$

	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%)

(with current theoretical uncertainties)

- Similar expectations from CMS

Summary of Higgs with 300 / 3000 fb^{-1}

300 fb^{-1} at 14 TeV

- m_H at 100 MeV
- Disentangle Spin 0 vs Spin 2 and main CP component in ZZ^*
- Relative precisions on couplings
  - Z, W, b, τ — 10-15%
  - t, μ — 2-3 σ observation
  - $\gamma\gamma, gg$ — 5-11%

3000 fb^{-1} at 14 TeV

- m_H at 50 MeV
- More precise studies of Higgs *CP* sector
- Relative precisions on couplings
  - Z, W, b, τ, t, μ — 2-10%
  - $\gamma\gamma, gg$ — 2-5%
  - $H \rightarrow HH > 3$ σ observation with CMS/ATLAS combined

(assuming sizeable reduction of theoretical errors)

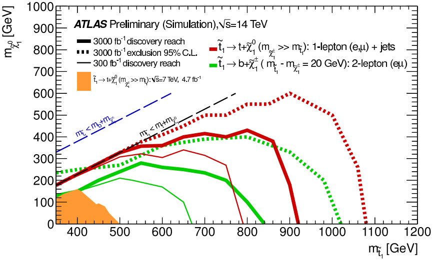
- LHC upgrades are crucial step towards precision tests of the nature of the newly discovered boson

Search for new physics at higher mass scale

SUSY

- 300 fb^{-1} / 3000 fb^{-1} (HL-LHC) at 14 TeV extends mass reach
- HL-LHC gives us...
- Sensitivity on squarks/gluinos
  - 3 TeV limit on squarks
  - 2.5 TeV limit on gluinos
  - $\sim$ 400-500 GeV rise in sensitivity with respect to 300 fb^{-1}
- Discovery potential on $\chi_1^{\pm}\chi_2^0$ production
  - chargino mass of $\sim$ 800 GeV for χ_1^0 masses below $\sim$ 300 GeV.

- Search for $\tilde{t} \rightarrow t + \chi_1^0$ and $\tilde{t} \rightarrow b + \chi_1^{\pm}$
- Naturalness requires sub-TeV $\tilde{t}$



- Limit up to $\sim$ 1.1 TeV, discovery up to $\sim$ 0.9 TeV with HL-LHC
- $\sim$ 200 GeV increase in sensitivity compared to 300 fb^{-1}

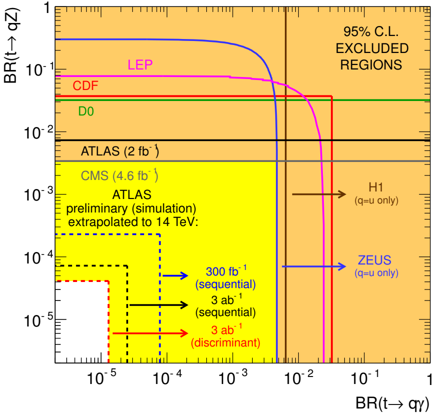
Search for new physics at higher mass scale

Exotics

- Expected sensitivity on high-mass resonances

model	300 fb^{-1}	3000 fb^{-1}
$g_{KK} \to t\bar{t}$	4.3 TeV	6.7 TeV
$Z'_{\rm SSM} \to ee$	6.5 TeV	7.8 TeV
$Z'_{\rm SSM} \to \mu\mu$	6.4 TeV	7.6 TeV

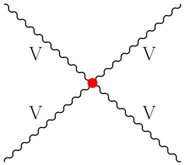
- Flavour-Changing Neutral Current in top decays
  - SM prediction on branching ratios $< 10^{-12}$
  - Some new physics model, e.g. SUSY with R-parity violation, enhance the FCNC decay branching ratios. Depending on the models, up to 10^{-4}



- Expected limits in the range between 10^{-5} and 10^{-4}

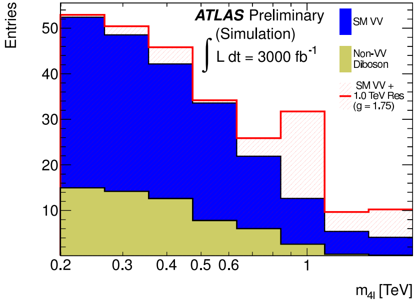
Vector boson scattering

- Higgs boson regularises the vector boson scattering cross-section



- Anomalous quartic couplings can appear in extensions of the SM

- m_{4l} of $ZZjj \rightarrow lllljj$ with and without ZZ resonance at 1 TeV.



model	300 fb^{-1}	3000 fb^{-1}
$m_{\text{resonance}} = 500$ GeV, $g = 1.0$	2.4 σ	7.5 σ
$m_{\text{resonance}} = 1000$ GeV, $g = 1.75$	1.7 σ	5.5 σ
$m_{\text{resonance}} = 1000$ GeV, $g = 2.5$	3.0 σ	9.5 σ

WHIZARD MC generator

- $O(10)\sigma$ measurement of $\sim$ TeV WW resonance with $WW \rightarrow l\nu jj$ mass.

Summary

- LHC experiments entered the era of Higgs-like boson measurement
- 300 fb^{-1} at 14 TeV enables us
  - to measure the properties of the Higgs-like boson
  - to explore higher mass scale
- 3000 fb^{-1} at 14 TeV will allow us
  - to perform more precise measurement of the Higgs properties
  - to extend mass reach for new physics searches
  - to explore vector boson scattering