2014.08.25 Next steps in the Energy Frontier – Hadron collider at FNAL

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on be half of ATLAS and CMS collaboration

Prospects of Higgs and SM measurements at HL-LHC

Contents in this talk

- *Schedule towards HL-LHC*
  - Upgrade of LHC, ATLAS and CMS
- *Measurement of higgs*
  - Simulation framework and performance for each object
  - Prospect for individual and combined analysis for higgs coupling
  - What we can exploit from higgs couplings
  - BSM search related to higgs
- *Conclusion*

Towards HL-LHC (2025-2035)

- *So far*
  - $\sqrt{s}$ = 7-8 TeV
  - Bunch spacing = 50 ns
  - Luminosity: $L \sim 6 \times 10^{33}$ cm^{-2}s^{-1}
  - Pileup $\mu \sim 20$

$\sqrt{s}$ =13 TeV
Bunch spacing = 25ns

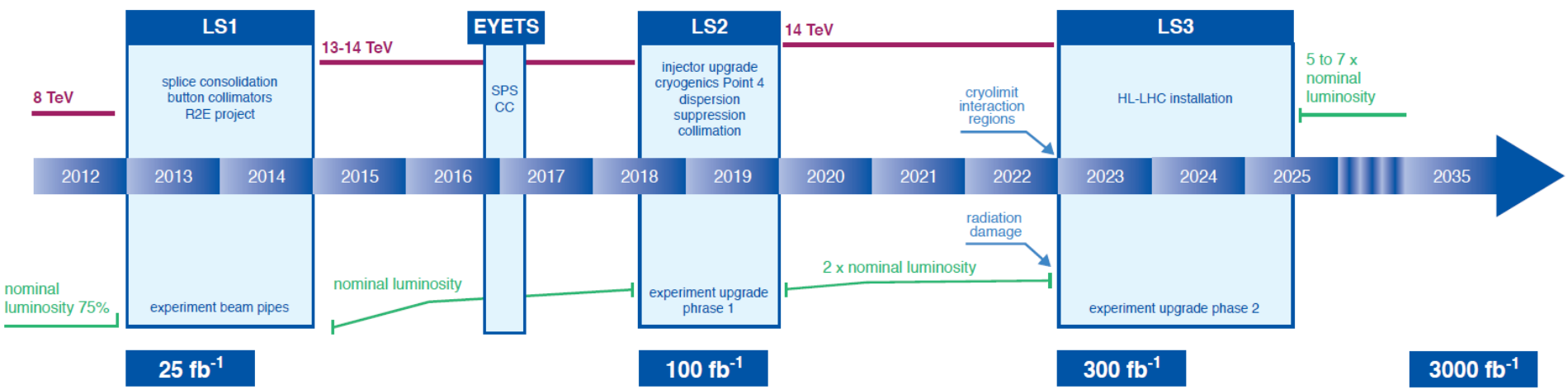
$\sqrt{s}$ =14 TeV
LHC injector upgrade

New interaction region layout
Crab cavity

$L \sim 1.6 \times 10^{34}$ cm^{-2}s^{-1}
$\mu \sim 40$

$L \sim 2 \times 10^{34}$ cm^{-2}s^{-1}
$\mu \sim 60$

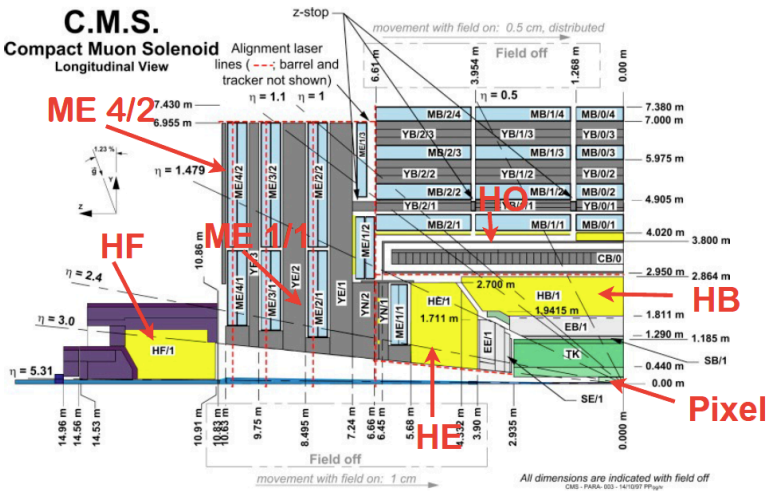
$L \sim 5 \times 10^{34}$ cm^{-2}s^{-1}
$\mu \sim 140$

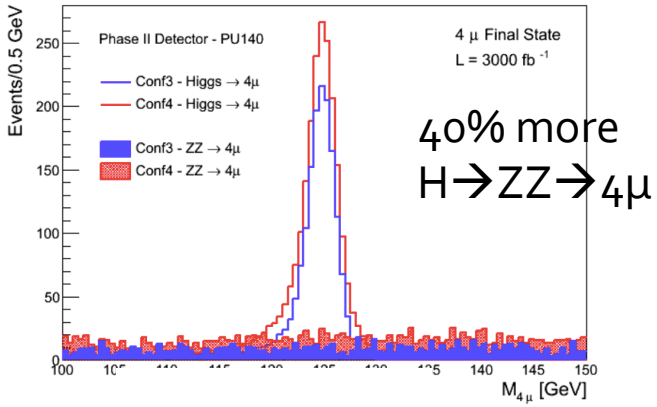


- *Keep detector performance at the same level as we have today*

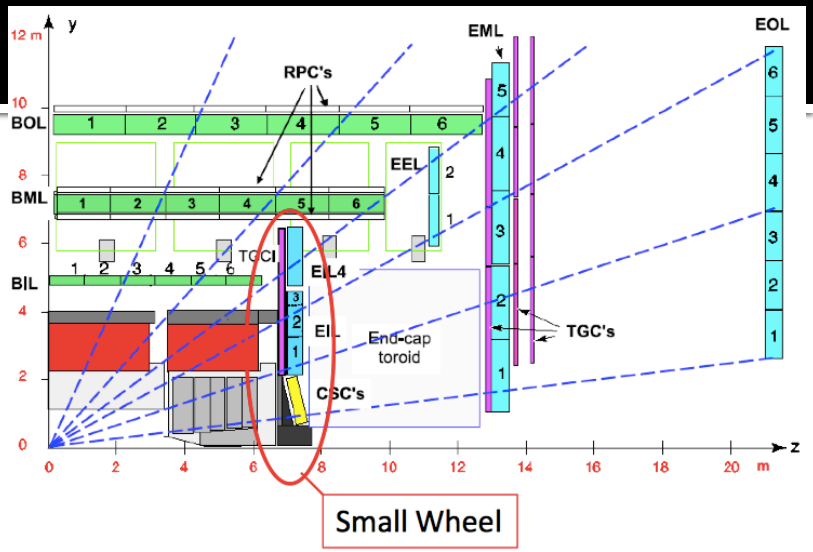
CMS upgrade

- *LS1*
  - Complete Muon coverage
  - Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD→SiPMs)
- *LS2*
  - New 4-layer Pixel detector
    - improves tracking eff. with lower fake rate
  - L1-Trigger upgrade
    - allows much improved algorithm for PU mitigation
  - HCAL electronics
- *LS3, considered upgrade*
  - Replace detectors due to radiation damage
    - Pixel, strip and endcap calorimeters
  - Enhanced coverage up to η=4
    - forward : tracker, calorimeter and muon detectors
  - Track trigger

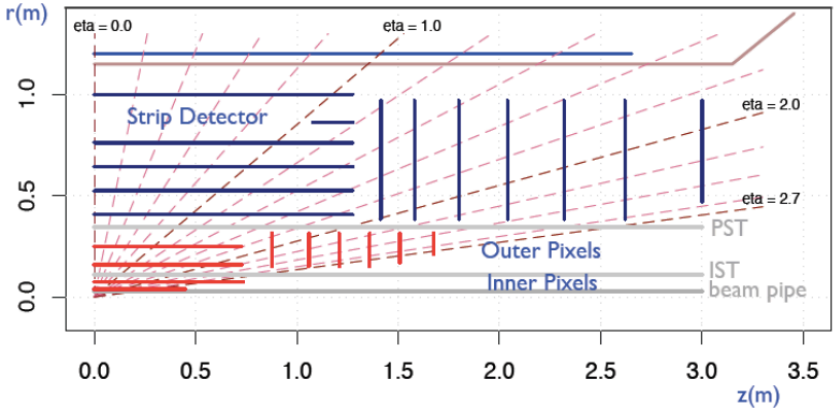




ATLAS upgrade



- *LS1*
  - New beam pipe
  - New insertable pixel b-layer and pixel services
  - Complete installation of muon chambers
- *LS2*
  - New Small Wheel (nSW) for the forward muon Spectrometer
  - Trigger upgrade
    - Topological L1-trigger processors
    - Higher granularity Calorimeter L1-Trigger
    - Fast TracKing (FTK) for L2-trigger



- *LS3, considered upgrade*
  - New tracking detectors
  - Calorimeter electronics and muon system upgrades
  - Two stage L0/L1 system from the present L1-trigger.

Simulation for HL-LHC

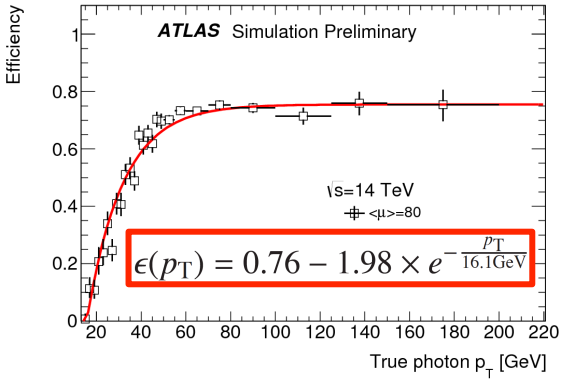
CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014

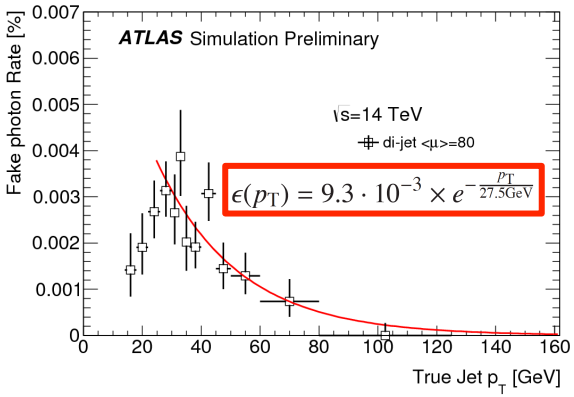
- *CMS*
  - Extrapolated from Run1 analysis for 8TeV
    - scaling signal and background event yields for 14TeV
  - Use current geometry and assume detector upgrades keep current performance
    - no attempt to optimize the measurement in order to minimize the uncertainties
  - Uncertainty
    - Scenario 1: the same systematic uncertainties as Run 1
    - Scenario 2: experimental syst. unc. scaled by √(integ. lumi.), theory syst. unc. reduced by 50%
- *ATLAS*
  - Full G4 simulation for 14 TeV with $<\mu> = 80$ and 140 with the upgrade
    - Only for H→WW study, 8 TeV sample is used as CMS does
  - Detector performances for each object are derived and parameterized
    - generator-level MC sample is smeared by the parameterized detector performance.
    - object selections are changed from Run1 analysis due to pile up
  - Basically the same as Run 1 for other systematic uncertainties
    - Uncertainties from data-driven estimates are scaled with √(integ. lumi.)
- *In this talk, Scenario 1 of CMS is compared to ATLAS results*

Performance (γ, e, μ)

ATL-PHYS-PUB-2013-004 ATL-PHYS-PUB-2013-009

- *Photon*
  - Efficiency
    - *higgs*→*γγ* from gluon-gluon fusion with <*μ*>=80
    - Assuming improved algorithm keep this efficiency at <*μ*>=140
  - Fake photon
    - Di-jet samples with <*μ*>=80
    - Assuming improved algorithm keep this at <*μ*>=140 as well



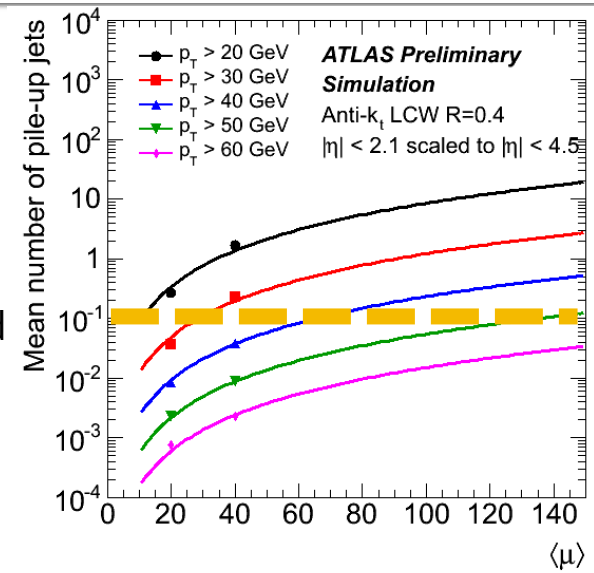


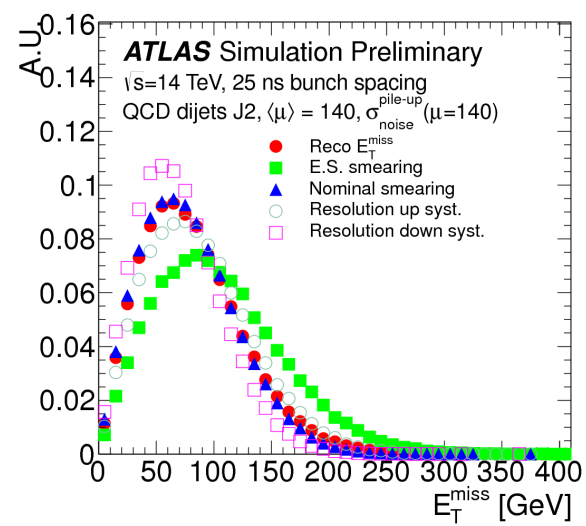
- *Electron*
  - The new Inner TracKer is implemented
  - Efficiency is calculated by using *Z*→*ee* sample
  - Fake electron is estimated by using di-jet sample
  - Energy resolution is the same as run1 performance
- *Muon*
  - The new tracker and the muon system are combined for parameterization
  - 80% efficiency for the isolation is estimated for leptons with $p_T < 20$ GeV
    - e.g. 90% at $p_T \sim 10$ GeV for Run 1 performance.

Performance (jet, E_T^{miss})

ATL-PHYS-PUB-2013-004 ATL-PHYS-PUB-2013-009

- *Jets*
  - Extrapolated from dijet MC
    - Event-by-event pile-up subtraction using jet area method
  - Jet energy resolution
    - μ dependence for noise term in $\frac{\sigma_{p_T}}{p_T} = \sqrt{\frac{N^2}{p_T^2} + \frac{S^2}{p_T} + C^2}$ is parameterized
      - μ= 20 : 5GeV → μ=140 : 13 GeV
  - Jet p_T threshold
    - Determine as 1 additional jet in 10% of the events
      - μ= 20 : 20GeV → μ=140 : 50 GeV
  - Jet reconstruction efficiency
    - Extrapolated from di-jet sample with μ=20 - 40 for μ=140
- E_T^{miss}
  - ΣE_T parameterization making use of $Z' \rightarrow ttbar$ with μ=140
    - Physics process dependence ← minimum-bias sample
    - Variation of pile-up noise threshold ← μ=100 and 200
  - Validation with dijet sample
    - Good agreement can be seen



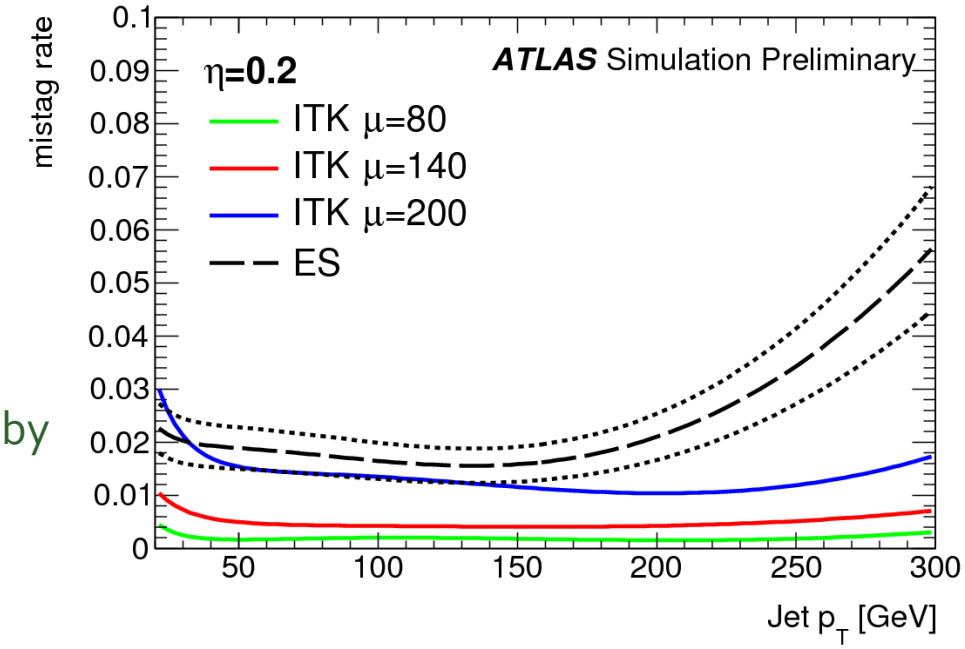


Performance (τ-identification, b-tag)

ATL-PHYS-PUB-2013-004 ATL-PHYS-PUB-2013-009

- *τ identification*
  - Leptonic decay
    - Performance for leptons and E_t^{miss} are based on the parameterization already discussed.
  - Hadronic decay
    - Latest hadronic τ identification and Higgs mass estimation algorithm are not included.
    - Assume that the performance tuned to 2012 data can be maintained

- *b-tagging*
  - The multivariate tagger MV1
    - impact parameter
    - secondary vertex
  - Monte-Carlo
    - ttbar at μ=140
  - b-tag eff. and mis-tag rate are affected by
    - primary vertex misidentification
    - contamination from pile-up tracks
    - increase of fake tracks



Properties of higgs

- *Individual channels*
  - *γγ, ZZ, WW, ττ, bb, μμ, Zγ and self-coupling*
- *Combined analysis*
  - *coupling, coupling ratio*

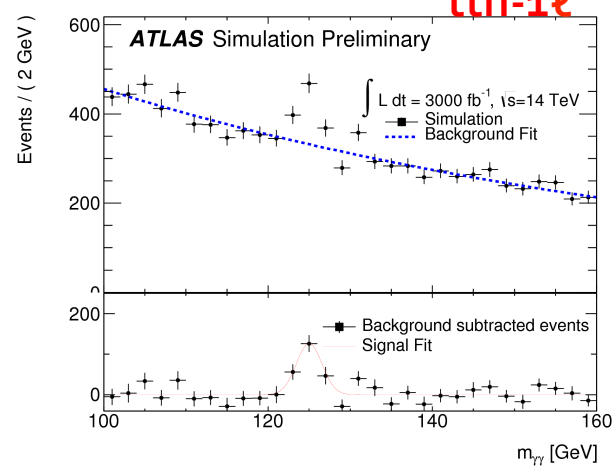
$higgs \rightarrow \gamma\gamma$

CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014 ATL-PHYS-PUB-2014-012

Currently ~25% uncertainty on μ; signal strength ratio to the SM prediction
Measurement of each higgs production will be possible.

- *At 3000 fb^{-1}, CMS expects 8% uncertainty for scenario 1.*
  - The same selection for objects as Run1
- *ATLAS expects 10% uncertainty with theory unc.*
  - Selection for two isolated photons
    - one photon with $p_T > 40$ GeV and the other with $p_T > 30$ GeV
  - Additional selections for each category;
    - tth : ~20% precision can be achieved

tth-1ℓ



category	# of Jets	# of lepton	
ttH	>1	1 or 2	$\lvert m_{\ell\ell}-m_Z\rvert > 15$ GeV for 2 lep
WH	0 or 1	1	
ZH	-	2	$\lvert m_{\ell\ell}-m_Z\rvert < 15$ GeV
ggF	0 or 1		
VBF	2		$\Delta\eta_{jj} > 4$ and $m_{jj} > 400$ GeV

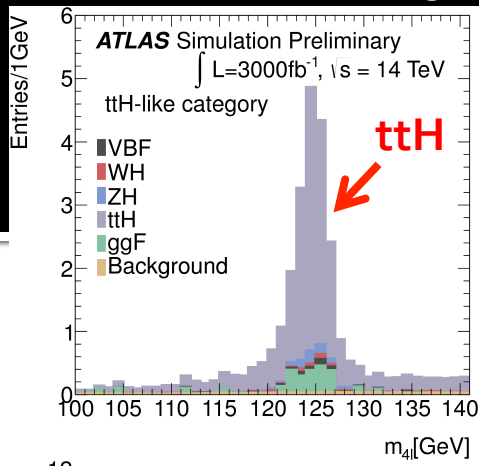
$\Delta\hat{\mu}/\hat{\mu}$ (%)			
Total	Statistical	Experimental	Theoretical
$^{+21}_{-17}$	$^{+13}_{-12}$	$^{+5}_{-4}$	$^{+17}_{-11}$
$^{+26}_{-25}$	$^{+21}_{-20}$	$^{+13}_{-12}$	$^{+10}_{-8}$
$^{+35}_{-31}$	$^{+32}_{-29}$	$^{+7}_{-7}$	$^{+12}_{-8}$
$^{+19}_{-14}$	$^{+3}_{-3}$	$^{+1}_{-1}$	$^{+19}_{-14}$
$^{+29}_{-29}$	$^{+18}_{-18}$	$^{+1}_{-1}$	$^{+23}_{-23}$

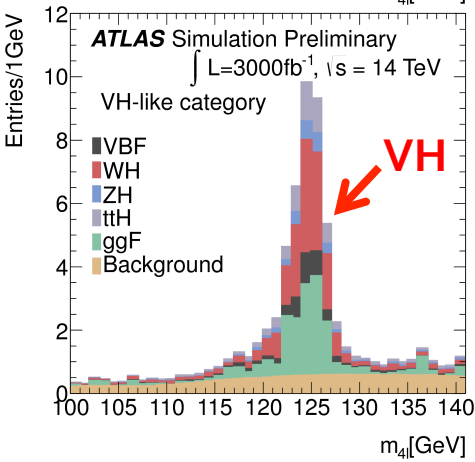
$higgs \rightarrow ZZ \rightarrow 4\ell$

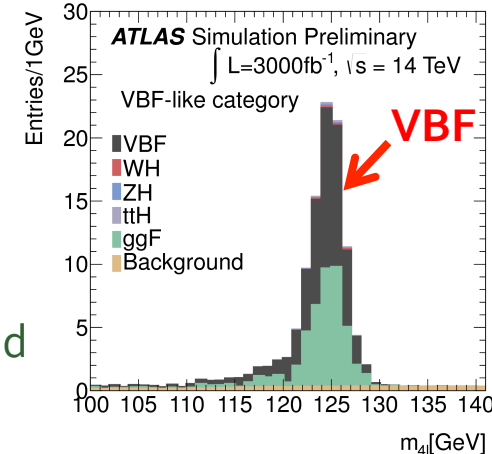
CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014

Currently ~25% uncertainty on μ
Measurement of each higgs production will be possible.

- *At 3000 fb^{-1}, CMS expects 7% uncertainty for scenario 1*
  - The same selection for objects as Run1
- *ATLAS expects 10 % uncertainty*
  - Selection for 4 leptons
    - Almost the same selection as Run1
    - 80% efficiency for isolation is assumed for leptons with $p_T < 20$ GeV
      - e.g. 90% efficiency for the isolation at $p_T \sim 10$ GeV for Run 1 performance
  - Additional exclusive classification following the order:
    - at least 1 b-jet + 1 lepton or at least 4 jets : tth 54% → 22%
    - 2 leptons with M_Z or 1 lepton with $p_T > 15$ GeV : Wh/Zh 107% → 39%
    - at least 2 jets with $\Delta\eta > 3$ and $m_{jj} > 350$ GeV : VBF 63% → 37%
    - everything else : ggF 15% → 13%
  - From 300fb^{-1} to 3000fb^{-1}, a factor of 2-3 improvement is expected





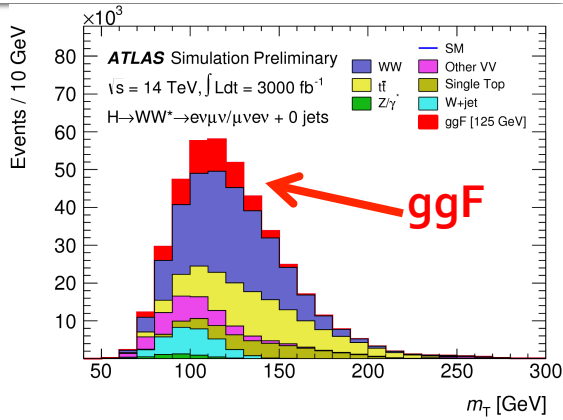


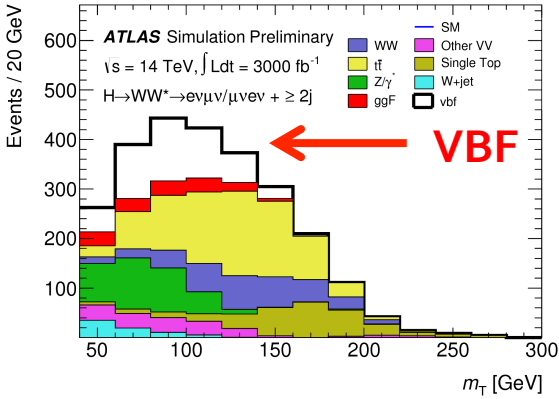
$higgs \rightarrow WW \rightarrow \ell\nu\ell\nu$

CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014

Currently ~25% uncertainty on μ

- *At 3000 fb^{-1}, CMS expects 7% uncertainty for scenario 1*
  - The same selection for objects as Run1
- *ATLAS expects ~10% uncertainty*
  - Contribution for ggF and VBF production are investigated
  - extrapolated from reconstructed events in 8TeV MC samples
    - parton distribution function reweighting
    - emulation of the ATLAS detector in the high pile-up environment
  - Jet thresholds tuning for pile-up and ttbar increase
    - ggF
      - $Njet = 0$
      - Jet $p_T > 35$ GeV
    - VBF
      - $Njet > 1$
      - Jet $p_T > 45$ GeV
      - veto central jet $p_T > 30$ GeV





	μ_{ggF}	μ_{VBF}	$\mu_{\mathrm{ggF+VBF}}$
300 fb^{-1}	$1^{+0.18}_{-0.15}$	$1^{+0.25}_{-0.22}$	$1^{+0.14}_{-0.13}$
3000 fb^{-1}	$1^{+0.16}_{-0.14}$	$1^{+0.15}_{-0.15}$	$1^{+0.10}_{-0.09}$

$higgs \rightarrow \tau\tau$

CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014

Currently ~30% uncertainty on μ

- *At 3000 fb^{-1}, CMS expects 8% uncertainty for scenario 1*
  - The same selection for objects as Run1
- *ATLAS expects 19% uncertainty*
  - Currently Cut-based analysis
    - will be updated by MVA analysis
  - Using only 2 channels
    - VBF $higgs \rightarrow \tau\tau \rightarrow \ell\ell$
      - Using parameterized performance for lepton and E_T^{miss}
    - VBF $higgs \rightarrow \tau\tau \rightarrow \ell h$
      - Used hadronic τ identification did not include latest algorithm
  - Other channels such as boosted categories and the Vh channels have not included yet.

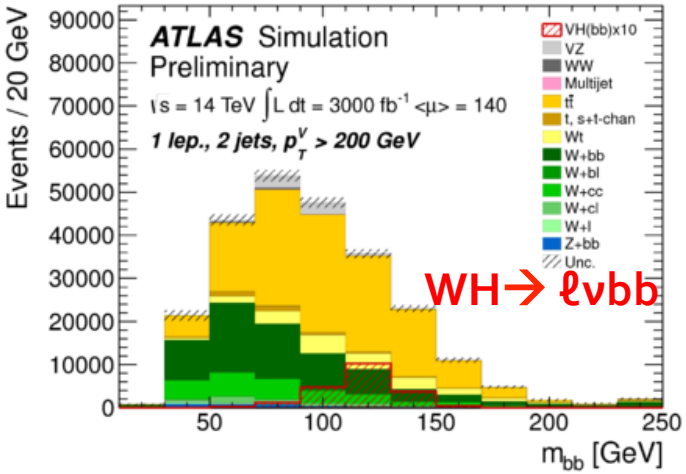
$\Delta\mu/\mu$	300 fb^{-1}		3000 fb^{-1}	
	All unc.	No theory unc.	All unc.	No theory unc.
$H \rightarrow \tau\tau$ (VBF-like)	0.22	0.16	0.19	0.12

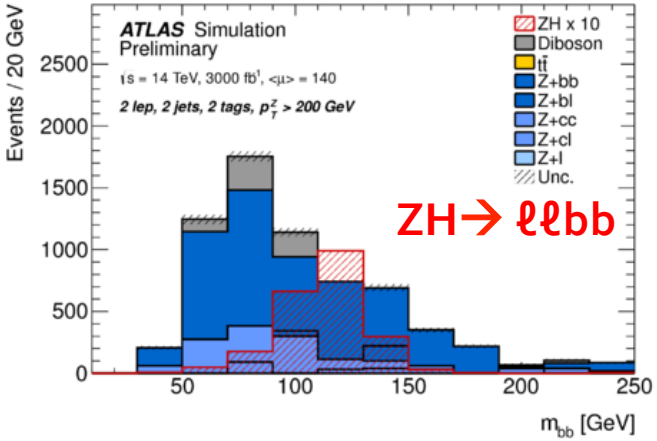
$higgs \rightarrow bb$

CMS-NOTE-2013-002 ATL-PHYS-PUB-2014-011

Currently ~50% uncertainty on μ

- *At 3000 fb^{-1}, CMS expects 7% uncertainty for scenario 1.*
  - The same selection for objects as Run1
- *ATLAS expects 19%*
  - $Wh \rightarrow \ell\nu bb$ and $Zh \rightarrow \ell\ell bb$
    - 2 b-jets
      - leading jet $p_T > 60$ GeV (45 GeV for Run1)
      - sub-leading jet $p_T > 40$ GeV (20 GeV for Run1)
    - 0 or 1 extra jet
      - $p_T > 30$ GeV (20 GeV for Run1)
  - *Further improvement can be possible at 3000 fb^{-1}*
    - multivariate analysis
    - jet calibration (global sequential calibration)
    - b-tagging : split into several categories
      - → uncertainty on μ of 14% can be achieved
  - $Zh \rightarrow \nu\nu bb$ channel can also be included.





$higgs \rightarrow \mu\mu$

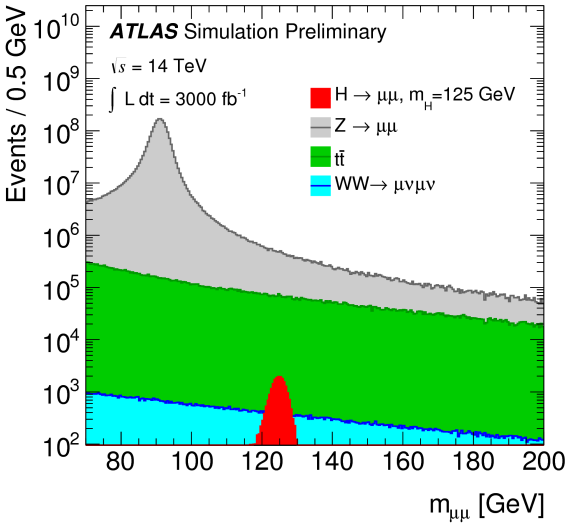
CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014

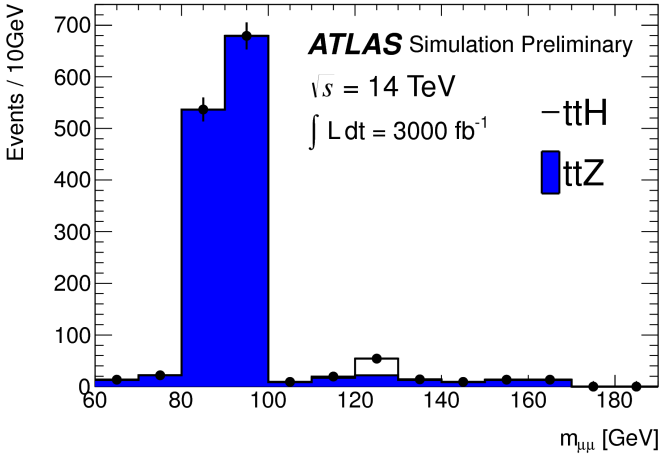
Current limit 7 times SM : Chance to measure coupling to 2nd generation fermion

- *At 3000 fb^{-1}, CMS expects 24% uncertainty for scenario 1.*
  - The same selection for objects as Run1
- *ATLAS expects 21% uncertainty*
  - $Z/\gamma \rightarrow \mu\mu$ is the main background for this analysis
  - Consider improved resolution and isolation efficiency
  - 3000 fb^{-1}, sensitivity is still statistically limited

$\mathcal{L}$ [fb^{-1}]	300	3000
Signal significance	2.3σ	7.0σ
$\Delta\mu/\mu$	46%	21%

- $tth \rightarrow \mu\mu$ category is also investigated
  - At least 4 jets
  - 33 signal and 22 background
  - Almost comparable sensitivity compared to $\gamma\gamma$ and ZZ

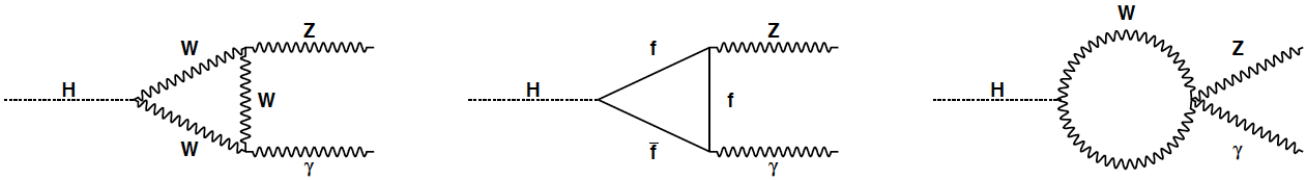




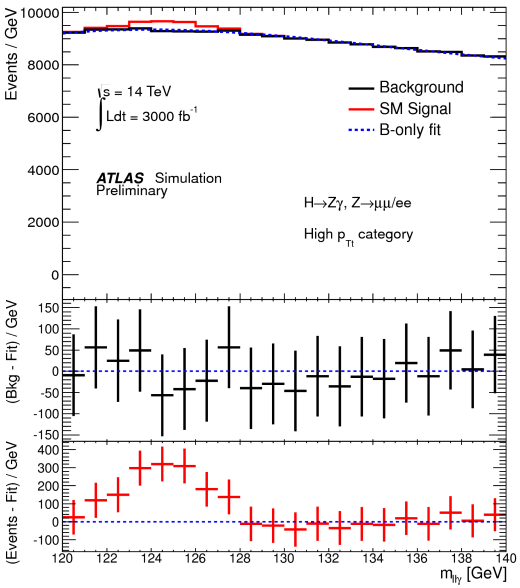
$higgs \to Z\gamma \to \ell\ell\gamma \ (\ell = e,\mu)$

CMS-NOTE-2013-002 ATL-PHYS-PUB-2014-006

$h \to Z\gamma$ and $h \to \gamma\gamma$ are possible only through loop, which is sensitive to new physics

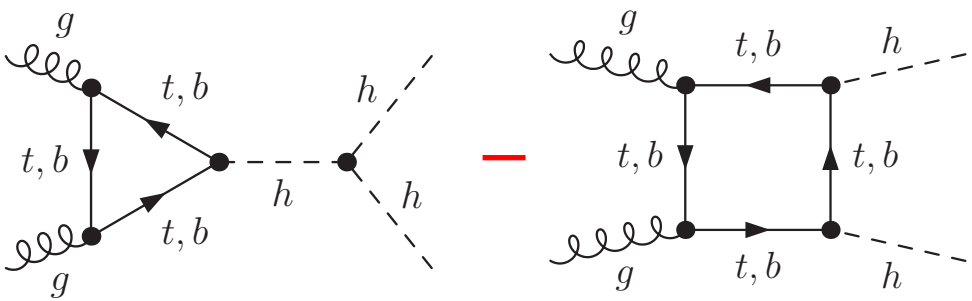


- *For 125 GeV Higgs, $Br(h \to Z\gamma \to \ell\ell\gamma) = 1.1 \times 10^{-4}$, e.g. $Br(h \to \gamma\gamma) = 2.3 \times 10^{-3}$*
  - Main background from $qq \to Z\gamma$, which is almost back-to-back reaction
- *In some models, $Br(h \to Z\gamma)$ and $Br(h \to \gamma\gamma)$ are not correlated*
  - Combined analysis can give information on new physics
    - Charged scalar boson
    - other electroweak singlets / triplets
- *At 3000 fb^{-1},*
  - CMS expects 24% uncertainty
  - Atlas expects 30% uncertainty
- *Sensitivity is still statistically limited*
  - factor 2 improvement from 300 fb^{-1} is possible

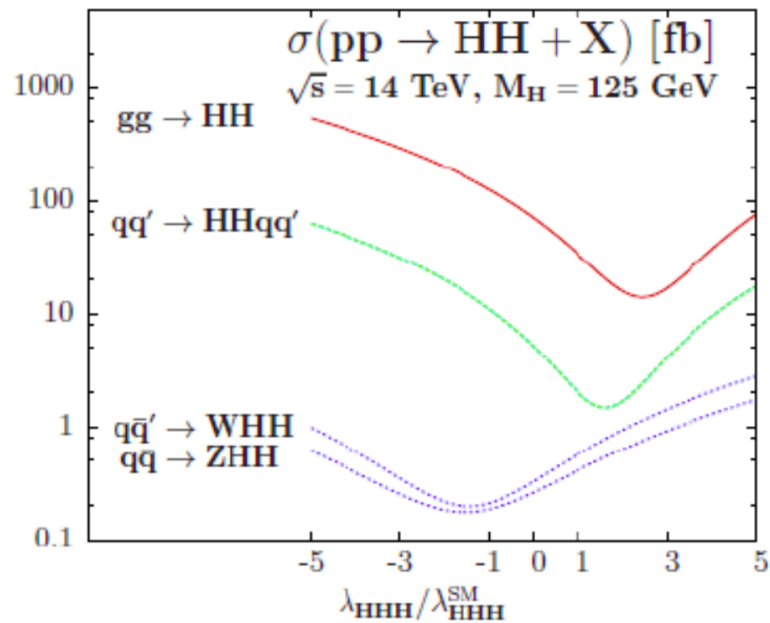


higgs self-coupling

- *Only way to investigate the higgs potential*
  - deviation from the SM expectations are hint of new physics
- *Small cross-section at M_h=125 GeV, $\sigma = 40 \pm 3$ fb*
  - Destructive interference between two diagrams:



  - It is likely that we need to combine all branches
    - $hh \to bbWW$
    - $hh \to bb\gamma\gamma$

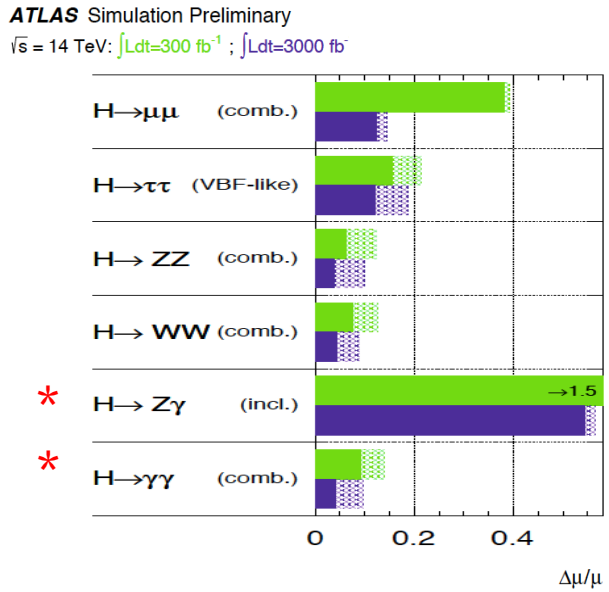


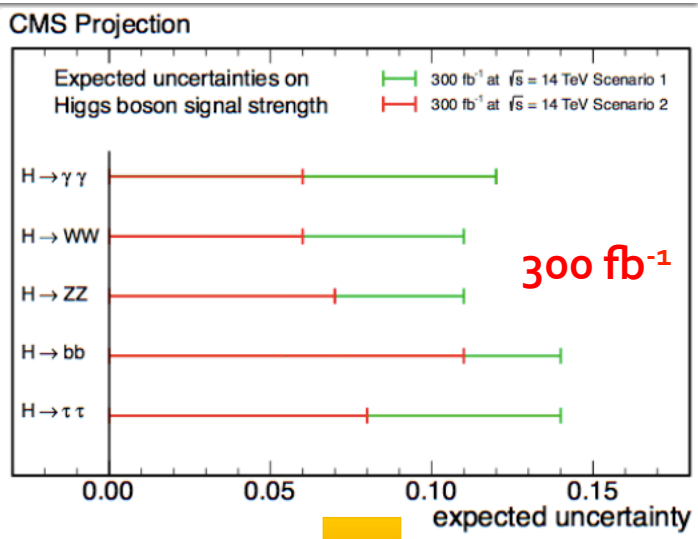
- *If λ_{hhh} could be 0 or negative value,*
  - Cross section increases by more than factor 2
- *Studies for many channels have been investigated.*

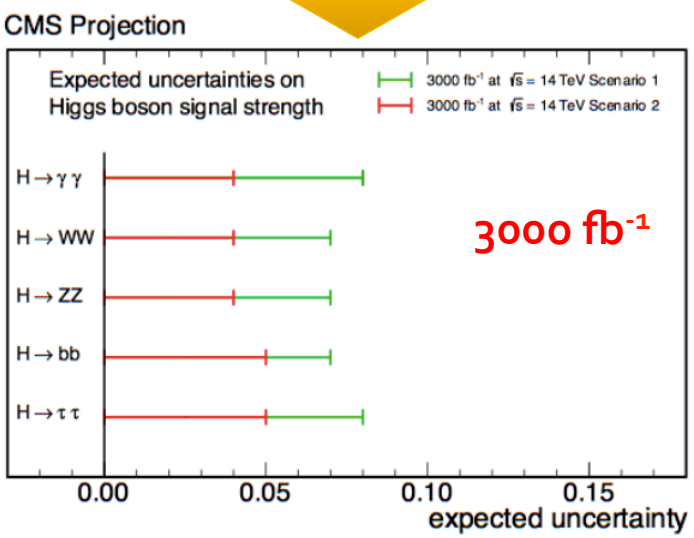
Signal strengths : $\mu=\sigma/\sigma_{SM}$

CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014

- *HL-LHC can reach accuracy ~ 10% on μ*
  - CMS
    - Scenario1 : same systematic uncertainties as in 2012
  - ATLAS
    - hashed area shows theory uncertainty.
    - not contain new bb, $Z\gamma$ or $\gamma\gamma$ (VH,ttH) projections *





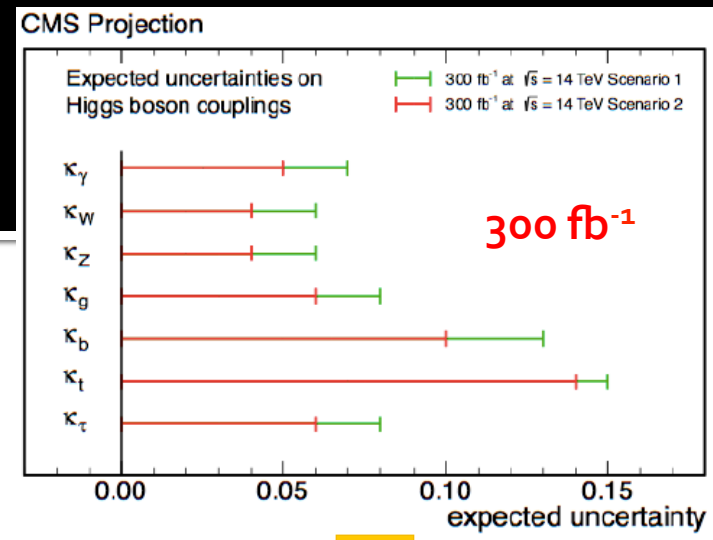


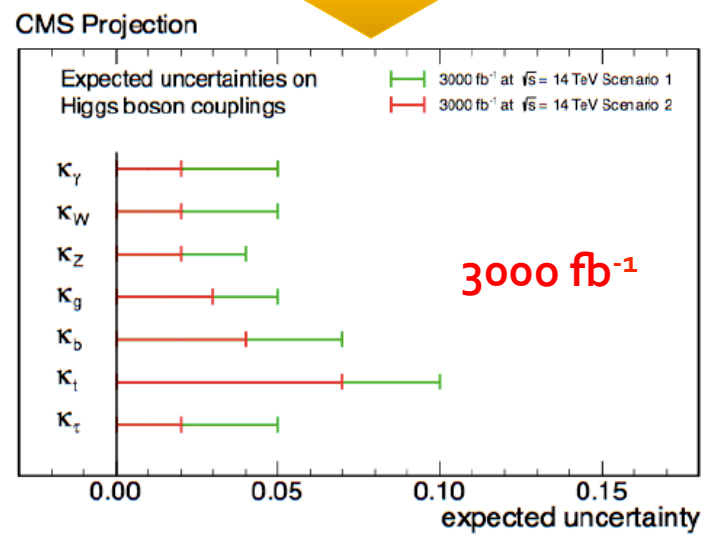
- *A factor of 2 improvement can be expected.*

Couplings

CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014

- *9 different coupling scale factors*
  - Tree level
    - κ_W, κ_Z, κ_μ, κ_τ, κ_b, κ_t
  - Loop induced
    - κ_γ, κ_g, $\kappa_{Z\gamma}$
- *Total width Γ_h is assumed to be sum of SM widths*
  - assume no new invisible channel
  - *higgs→cc* is 5% unmeasured contribution
    - CMS : Assumed to scale with bb
    - ATLAS : Assumed to scale with ττ
      - since *higgs→bb* prospect was not ready at that time
      - not contain new bb, $Z\gamma$ or $\gamma\gamma$ (VH,ttH) projections*
  - *300fb^{-1}→3000fb*



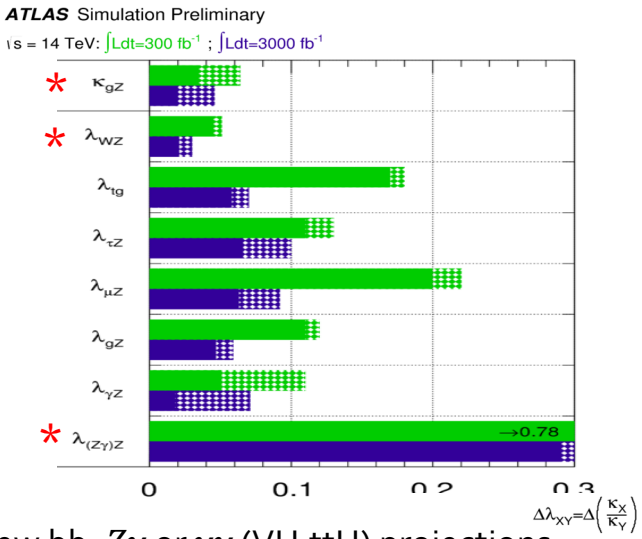


	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	κ_μ	$\kappa_{Z\gamma}$
ATLAS	13 → 9	8 → 6	8 → 6	11 → 7	*	22→10	18→15	23→11	79→30*
CMS	7 → 5	6 → 5	6→4	8 → 5	13→7	15→10	8→5	23→8	40→12

Couplings ratios

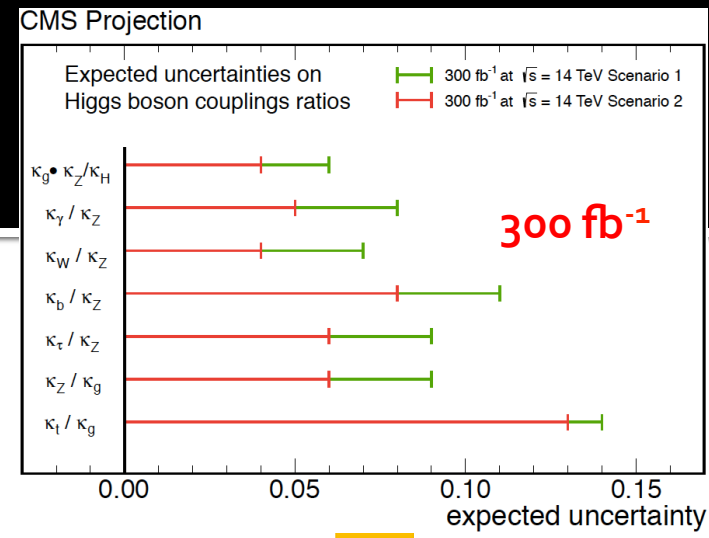
CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014

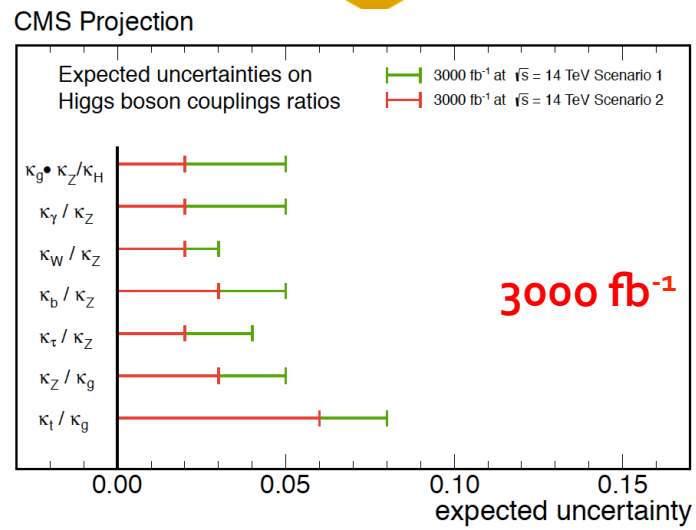
- *Several experimental syst. cancel in the ratios*



*not contain new bb, $Z\gamma$ or $\gamma\gamma$ (VH,ttH) projections

- *HL-LHC can reach accuracy on coupling ratio ~ 5%*
  - could reach a few % precision even for fermions
  - *300fb^{-1} → 3000fb*





	$\kappa_g\kappa_Z/\kappa_h$	κ_W/κ_Z	κ_γ/κ_Z	κ_g/κ_Z	κ_b/κ_Z	κ_τ/κ_Z	κ_μ/κ_Z	κ_t/κ_g	$\kappa_{Z\gamma}/\kappa_Z$
ATLAS	6→5*	5→3*	11→7	12→6	*	13→10	22→9	18→7	78→30*
CMS	5→5	7→3	8→5	9→5	11→5	9→4	23→8	14→8	42→12

What we can exploit from higgs coupling

- *Composite higgs*
- *Additional electroweak singlet*
- *2HDM including MSSM*

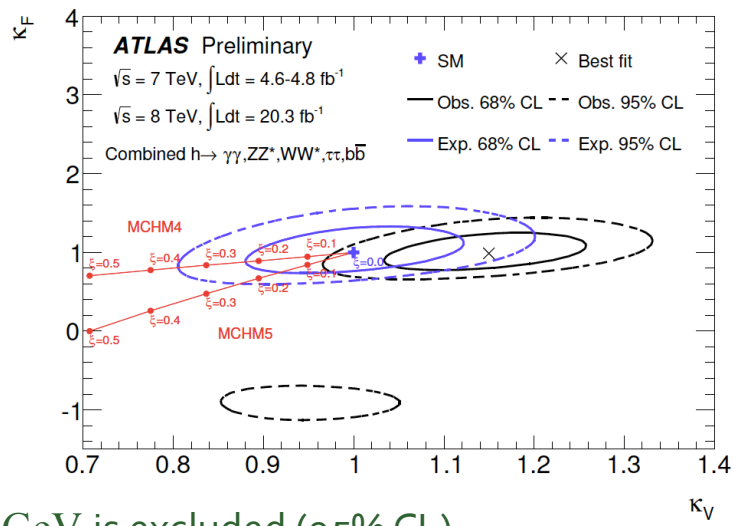
Composite higgs

CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-015

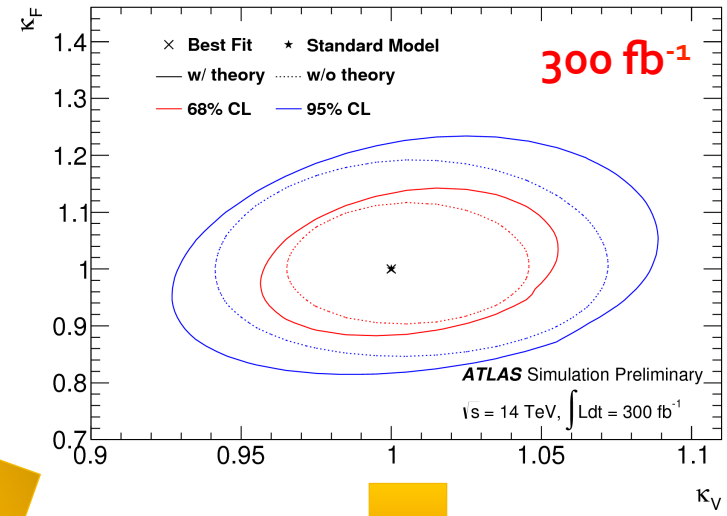
- *Minimal Composite higgs Models*
  - Another possible explanation for the naturalness problem
  - Characterized by $v=246$ GeV and compositeness scale, f;

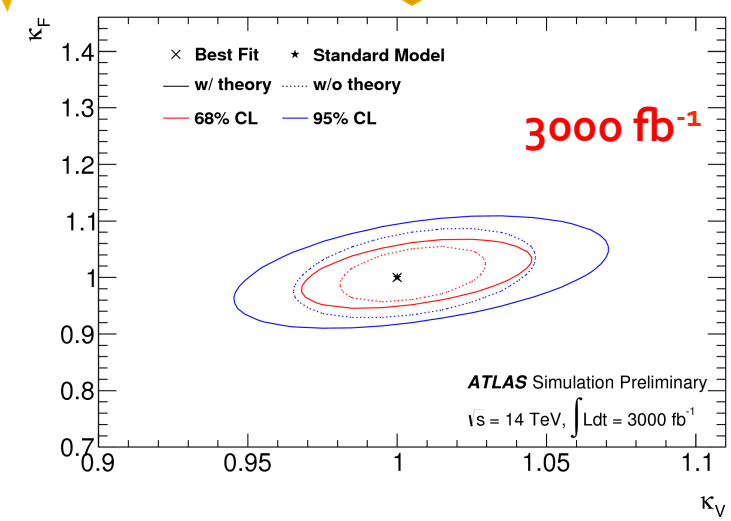
$$\xi = v^2/f^2$$

- *MCHM4* : $\kappa = \kappa_V = \kappa_F = \sqrt{1-\xi}$
  - Couplings to vector bosons & fermions modified from SM



- $f < 710$ GeV is excluded (95% CL)





- *Stringent test can be achieved at HL-LHC*

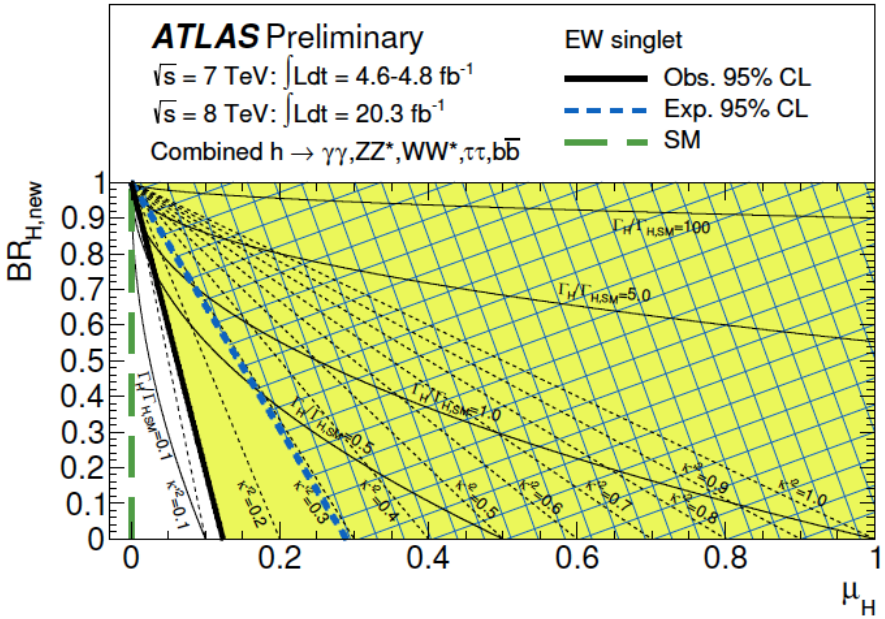
Additional electroweak singlet

ATL-PHYS-PUB-2013-015

- *The simplest extension to the SM higgs sector*
  - providing a possible answer to the dark matter problem
  - EW singlet field is added (two CP-even Higgs bosons, h and H)
  - Coupling for the new EW singlet, κ', can be obtained with signal strength μ for SM higgs;

$$\kappa'^2 = 1 - \mu_h$$

  - observed 95% CL upper limit of $\kappa' < 0.12$

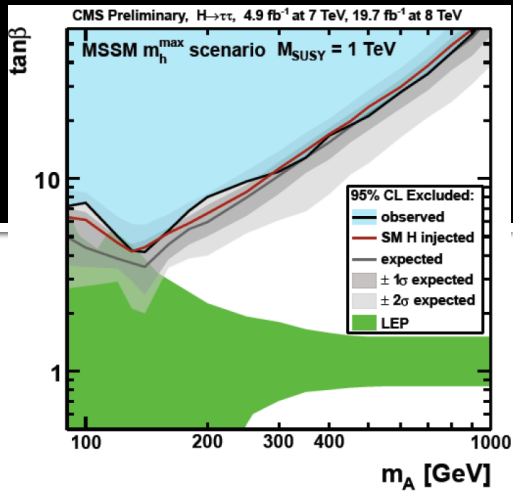


ATLAS-CONF-2014-010

- *Achievable sensitivity*
  - ~15 % : Current precision on μ_h
  - 3.2 % : 300 fb^{-1}
  - 2.5 % : 3000 fb^{-1}

- *If theory unc. is significantly reduced, HL-LHC can search κ' down to 0.016*

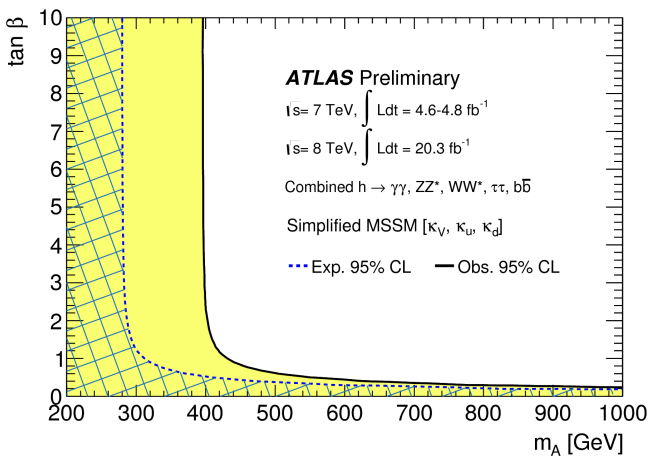
2HDM including MSSM

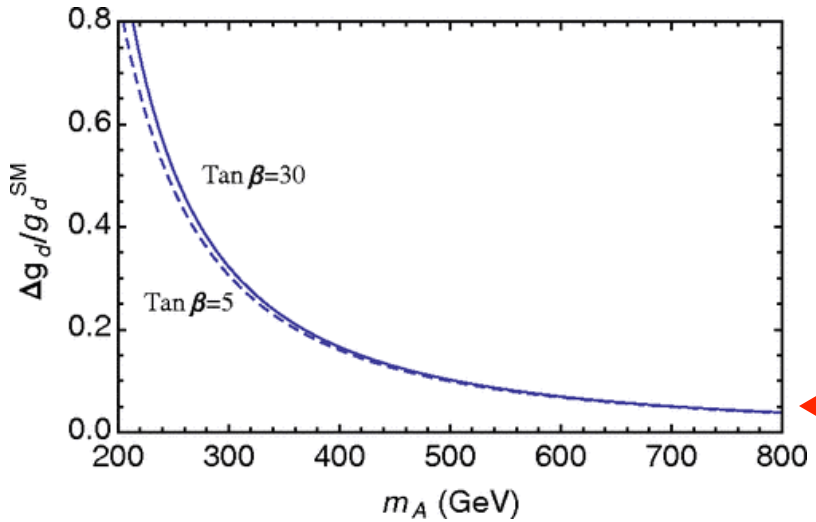


CMS-PAS-HIG-13-021

- *SM higgs sector is extended by an additional doublet*
  - Large deviation of the coupling is predicted
  - Depending on CP-odd Higgs mass, m_A , and $tan\beta$
  - $m_A < 140$ GeV is excluded by direct search
  - $m_A < 400$ GeV is constrained by the higgs coupling measurements
    - Assuming simplified MSSM

ATLAS-CONF-2014-010





Phys. Rev. D **86**, 095001

← 5%

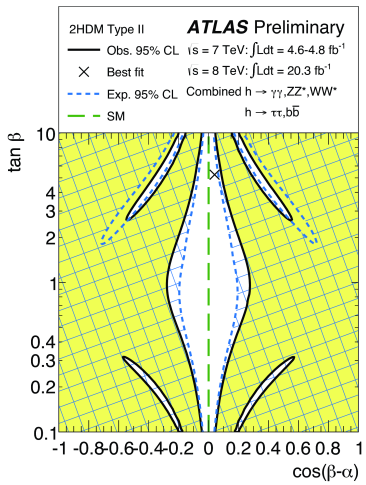
- Even m_A with 800 GeV makes +5% deviation for the down-type fermion
  - the vector bosons and the up-type fermion have negative deviation (-1% ~ 0%)

- *Taking the ratio, e.g. κ_b/κ_Z , with a few % precision can probe this !!*

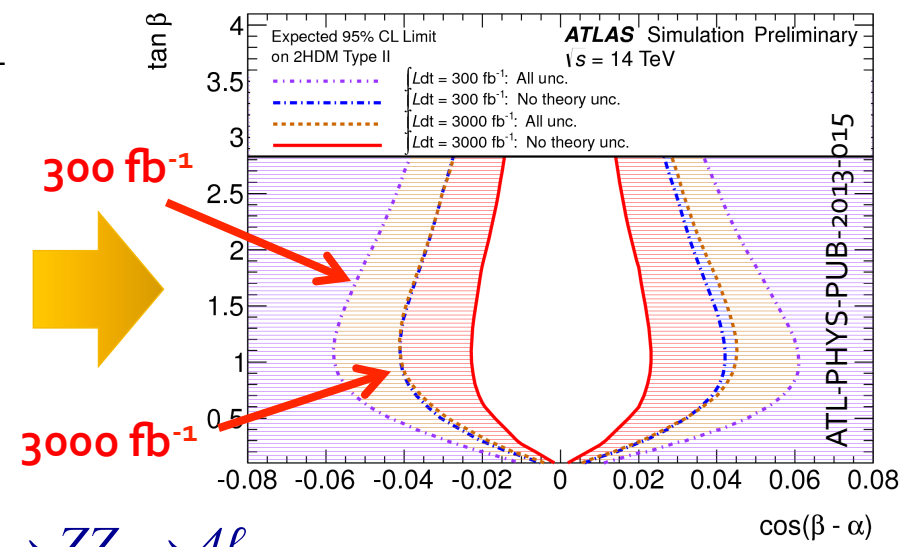
2HDM including MSSM

CMS PAS FTR-13-024 ATL-PHYS-PUB-2013-015 ATL-PHYS-PUB-2013-016

- *cos(β-α)* v.s. *tanβ*
  - $\kappa_V = \sin(\beta-\alpha)$
  - *cos(β-α)* at *tan β ~ 1*
    - current limit : 0.2
    - → at 300 fb^{-1} : 0.06
    - → at 3000 fb^{-1} : 0.04

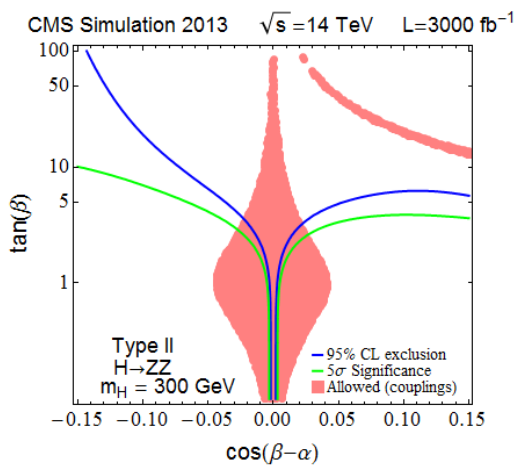


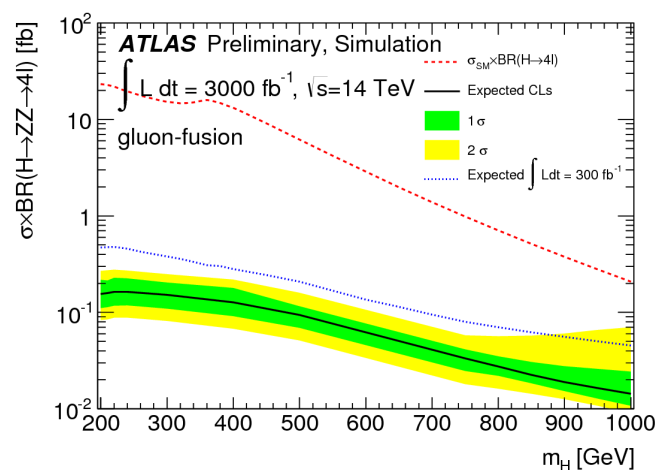
ATLAS-CONF-2014-010



ATL-PHYS-PUB-2013-015

- *For low tanβ region, heavy higgs search $H \to ZZ \to 4\ell$*
  - *provide complementary sensitivity to coupling studies*





Direct BSM searches related to higgs

- *BSM in vertex of higgs* $\rightarrow ZZ \rightarrow 4\ell$
- *higgs* $\rightarrow$ *invisible*
- *Top* $\rightarrow$ *Charm* + *higgs*
- *Vector boson scattering*

BSM in vertex of higgs → ZZ → 4ℓ

CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-013

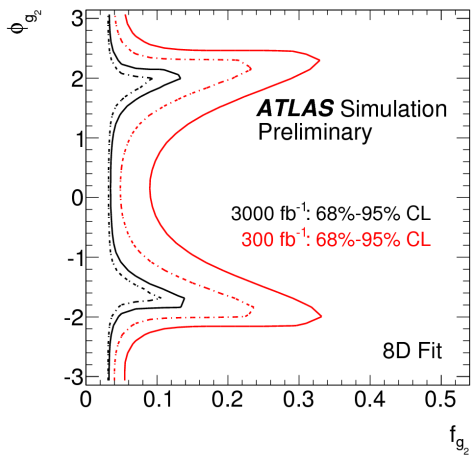
- *CMS and ATLAS have investigated presence of BSM in vertex*
  - Strongly favor $J^P=0^+$ SM quantum numbers
  - General amplitude of interaction between a spin-0 boson and two spin-1 gauge bosons:

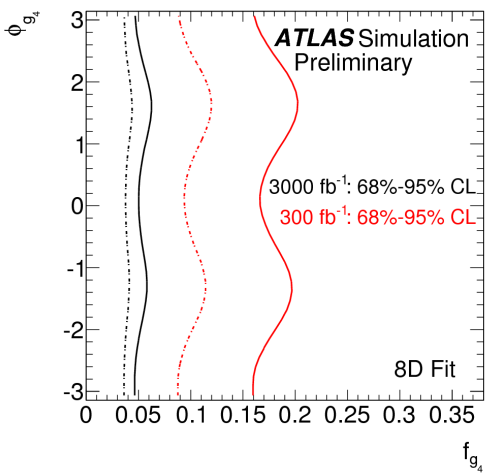
$$A(X \to VV) \sim (a_1 M_X^2 g_{\mu\nu} + a_2 (q_1+q_2)_\mu (q_1+q_2)_\nu + a_3 \varepsilon_{\mu\nu\alpha\beta} q_1^\alpha q_2^\beta) \varepsilon_1^{*\mu} \varepsilon_2^{*\nu}$$

CP-even : SM Higgs CP-even : BSM in loop CP-odd : BSM boson

- *Relative coupling strength to standard model*
  - Current limit for CP-odd BSM boson : $a_3 < 0.58$
  - $300fb^{-1} \rightarrow 3000fb^{-1}$

	CP-even : a_2 BSM in loop	CP-odd : a_3 BSM boson
ATLAS	0.29 → 0.12	0.15 → 0.037
CMS	--	0.13 → 0.04

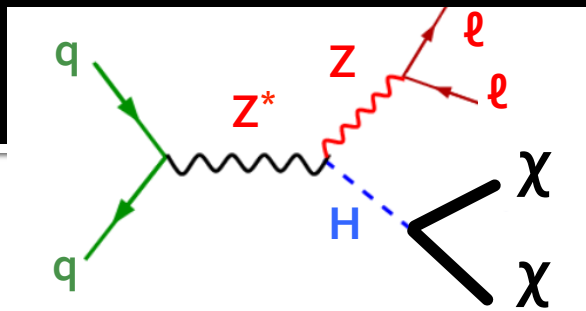




  - Factor 2-3 improvement with HL-LHC

higgs → invisible

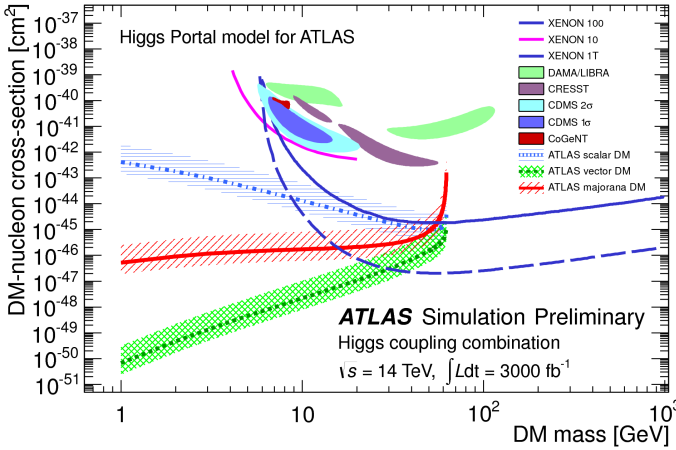
CMS-NOTE-2013-002 ATL-PHYS-PUB-2013-014 ATL-PHYS-PUB-2013-015



Current limit : $Br(higgs \rightarrow invisible) < \sim 70\%$

- *$Zh \rightarrow \ell\ell$ + invisible / VBF $h \rightarrow$ invisible can directly search this BSM decay*
  - SM invisible decay : $Br(higgs \rightarrow ZZ \rightarrow 4\nu) = 0.12\%$
  - One of the possible candidates for invisible is dark matter
  - Complementary search can be achieved by summing up all the higgs coupling measurements
- *At 3000 fb^{-1},*
  - *CMS expects to search $Br(higgs \rightarrow invisible) \sim 17\%$ as scenario 1.*
  - *Atlas expects $Br(higgs \rightarrow invisible) \sim 16\%$*
    - E_T^{miss} threshold
      - *Z+jets* background drastically increases in the lowest E_T^{miss} bin
      - the highest E_T^{miss} bin has the best sensitivity

	ZH → ℓℓ + invisible	Higgs coupling meas.
ATLAS	32%→ 16%	28% → 15%
CMS	28% → 17%	18% → 11%



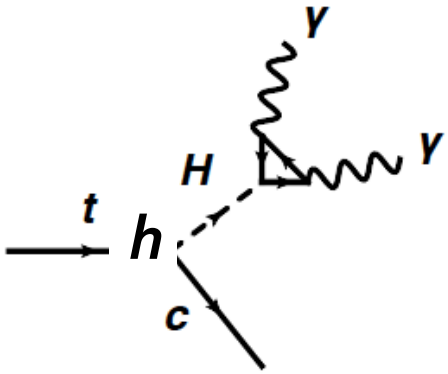
- *Sensitivity for dark matter within higgs portal models*

Top → Charm + higgs

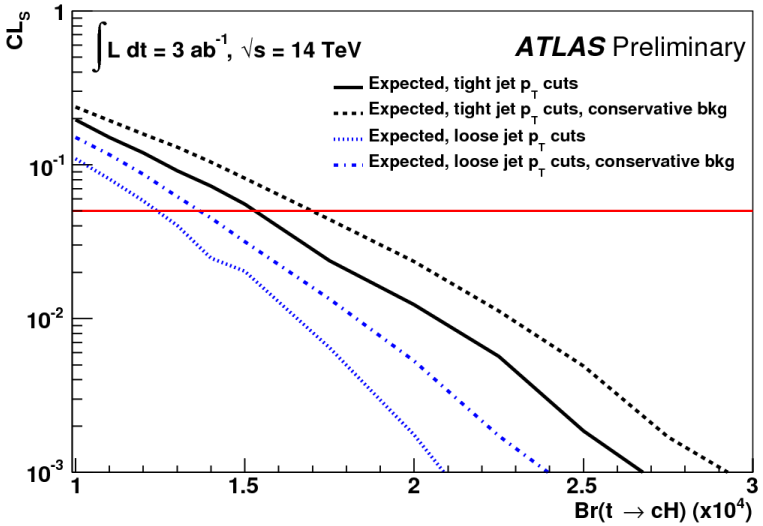
ATL-PHYS-PUB-2013-012

- *Flavor changing neutral current appears in 2HDM for example*
  - SM FCNC decays is GIM-suppressed, 3×10^{-15}.

	2HDM (Type Ⅲ)	Quark singlet	2HDM (Type Ⅰ)	2HDM (Type Ⅱ)	SM
$Br(t \to c + higgs)$	1.5×10^{-3}	4.1×10^{-5}	$\sim 10^{-5}$	10^{-5}	3×10^{-15}



  - 2HDM without explicit flavor conservation, Type Ⅲ, predicts large FCNC, 1.5×10^{-3}.
    - Same coupling for up-type and down-type quarks
    - Different coupling for leptons

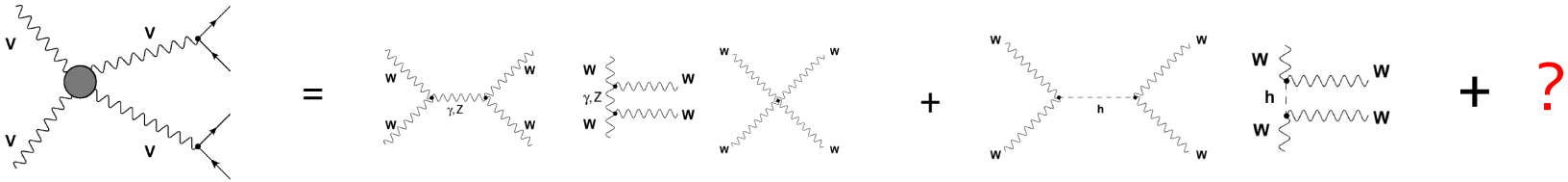


- *Object selections*
  - the same as the analysis for Run1
  - Discriminant variable is $\gamma\gamma + jet$ invariant mass
- *Expected limit at HL-LHC*
  - $Br(t \to c + higgs) = 1.7 \times 10^{-4}$ can be reached

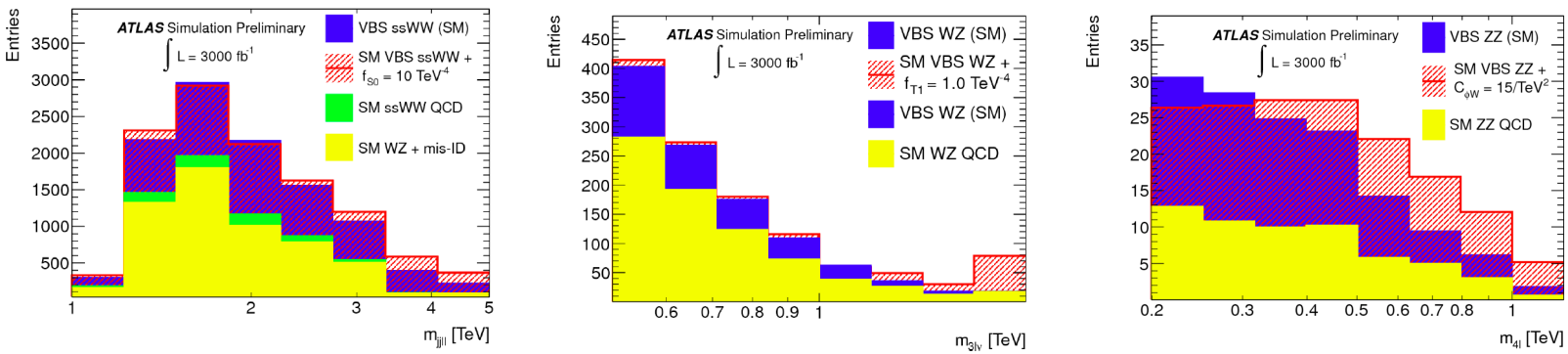
Vector boson scattering

CMS-PAS-FTR-13-006 ATL-PHYS-PUB-2013-006

- *Higgs preserves the unitarity of scattering amplitudes in $W_L W_L$ scattering*



- 300fb^{-1} is sufficient for 5σ observation for SM electroweak scattering
  - Anomalous quartic couplings have been investigated in WW, WZ and ZZ scattering.



  - 5σ discovery sensitivity (300fb^{-1} → 3000fb^{-1})

	$WWjj \to \ell\nu\ell\nu jj$ f_{S0}/Λ^4	$WZjj \to \ell\nu\ell\ell jj$ f_{T1}/Λ^4	$ZZjj \to \ell\ell\ell\ell jj$ $C_{\phi W}/\Lambda^2$
ATLAS	10TeV^{-4} → 4.5TeV^{-4}	1.3TeV^{-4} → 0.6TeV^{-4}	34TeV^{-2} → 16TeV^{-2}
CMS	---	1.0TeV^{-4} → 0.55TeV^{-4}	---

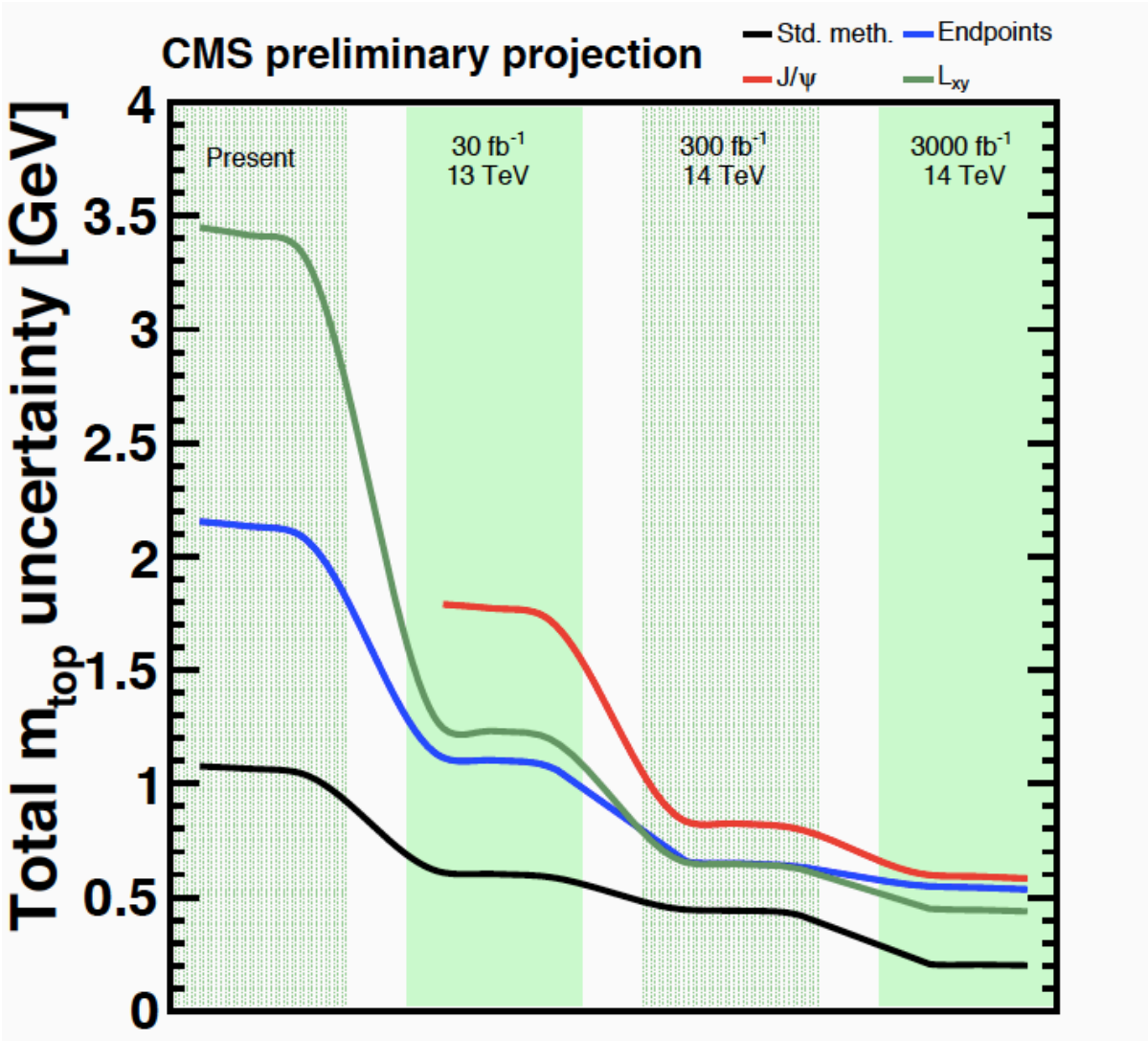
Conclusion

- *ATLAS and CMS upgrades are intended to keep the same performance as Run1*
- *Coupling measurement at HL-LHC will be 2 times more precise than with 300fb^{-1}*
  - Gauge bosons : a few percent level
    - Need theoretical improvement for further precision
  - Fermions including $higgs \to \mu\mu$: around 10%
    - There is room for improvement on flavor tagging, jet energy calibration, background modeling and so on
  - $higgs \to Z\gamma$: around 30%
    - This channels provide us complementary knowledge for new physics in loop
  - higgs self-coupling : study on going
    - If something strange happens in λ_{hhh}, production cross section could be enhanced very much.

Strict test for composite Higgs, additional singlet/doublet including MSSM and generation

- *Direct search for BSM related to higgs*
  - BSM in vertex of $higgs \to ZZ \to 4\ell$
  - $higgs \to invisible$
  - FCNC search via $Top \to Charm + higgs$
  - Vector boson scattering

complementary to coupling measurement

Thank you !

Top Quark Mass Uncertainty