ATLAS Higgs and Supersymmetry Physics Prospects at the High-Luminosity LHC

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On behalf of the ATLAS Collaboration

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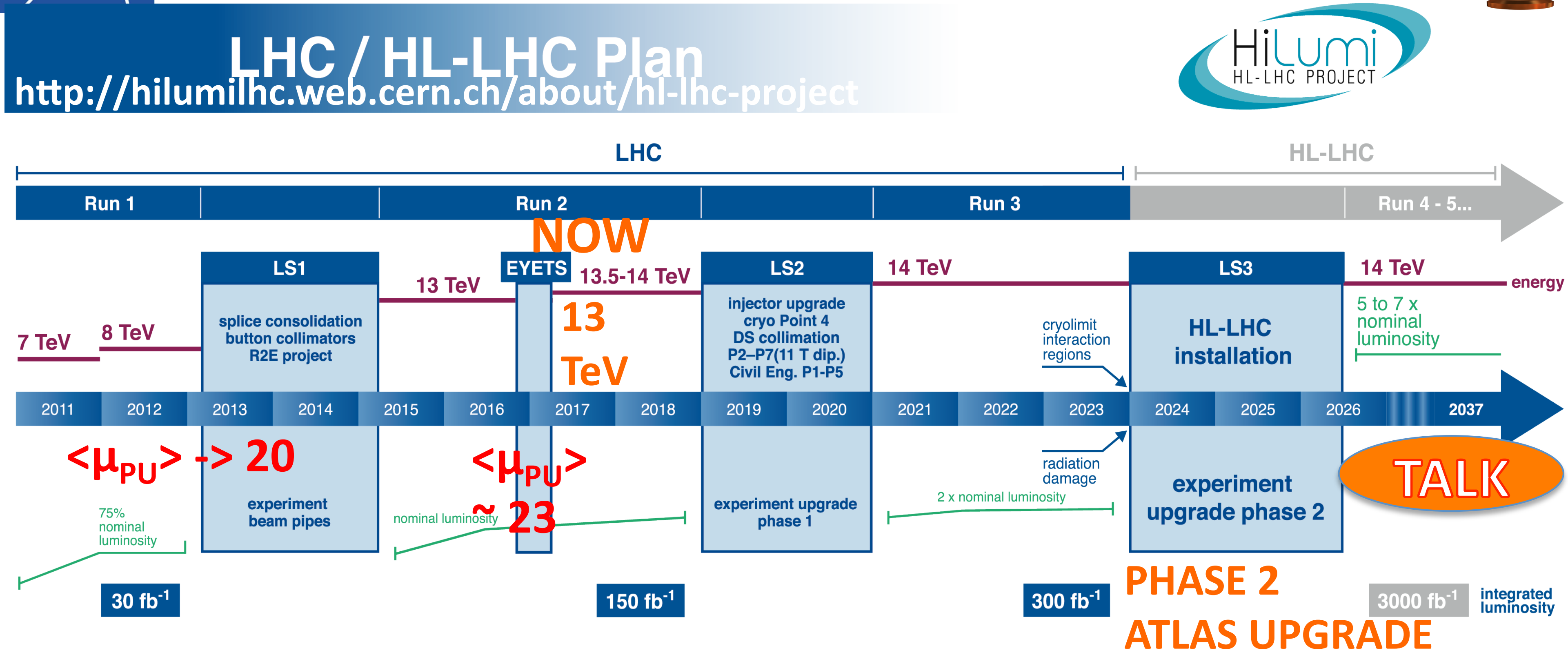
Outline

- The **High Luminosity**-LHC program
- **ATLAS Phase II Upgrade** program
- **Higgs** analysis prospect:
  - Higgs boson coupling
  - Higgs boson self-coupling
  - Higgs boson rare decays
  - VBF Higgs boson production
- **Supersymmetry** (SUSY) analysis prospect:
  - Stop pair direct production
  - Stau pair direct production
  - Chargino and neutralino direct production
- Conclusion

HL-LHC program



HL-LHC mode	Peak Luminosity (cm^{-2} s^{-1})	Mean number of interactions per bunch-crossing $\langle\mu_{PU}\rangle$	Integrated luminosity (fb^{-1})
Baseline	$5x10^{34}$	**140**	**3000**
Ultimate	$7.5x10^{34}$	**200**	4000

ATLAS Phase II Upgrade Program (2024-2026)

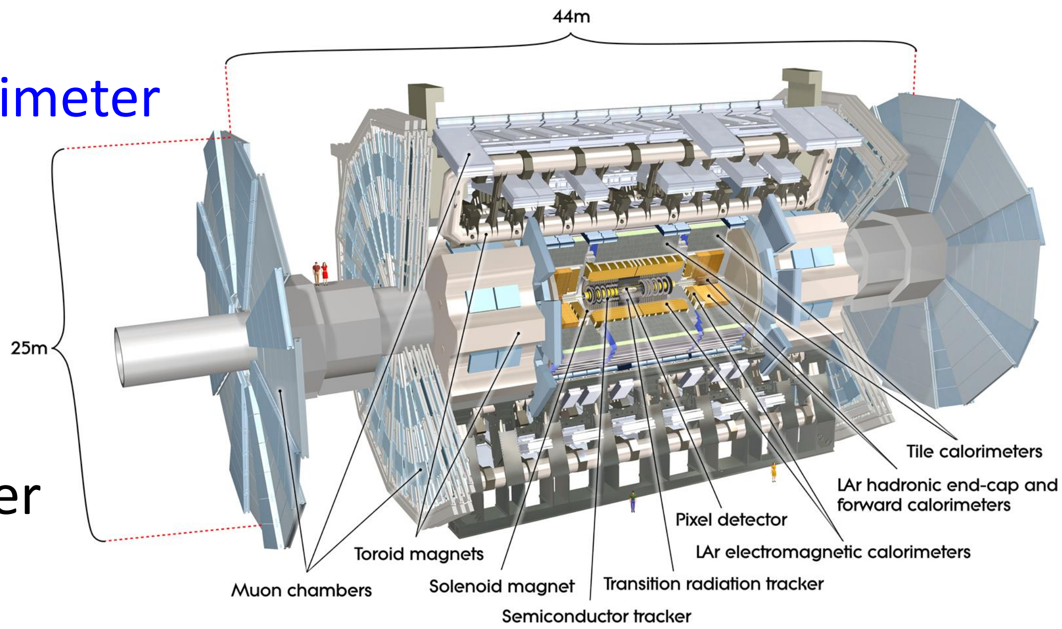
- ATLAS **Phase II upgrade:** for performance and degradation/limitation

-> **maximize the physics performance** and discovery potential of ATLAS

- increased pile-up - higher backgrounds - higher trigger rates

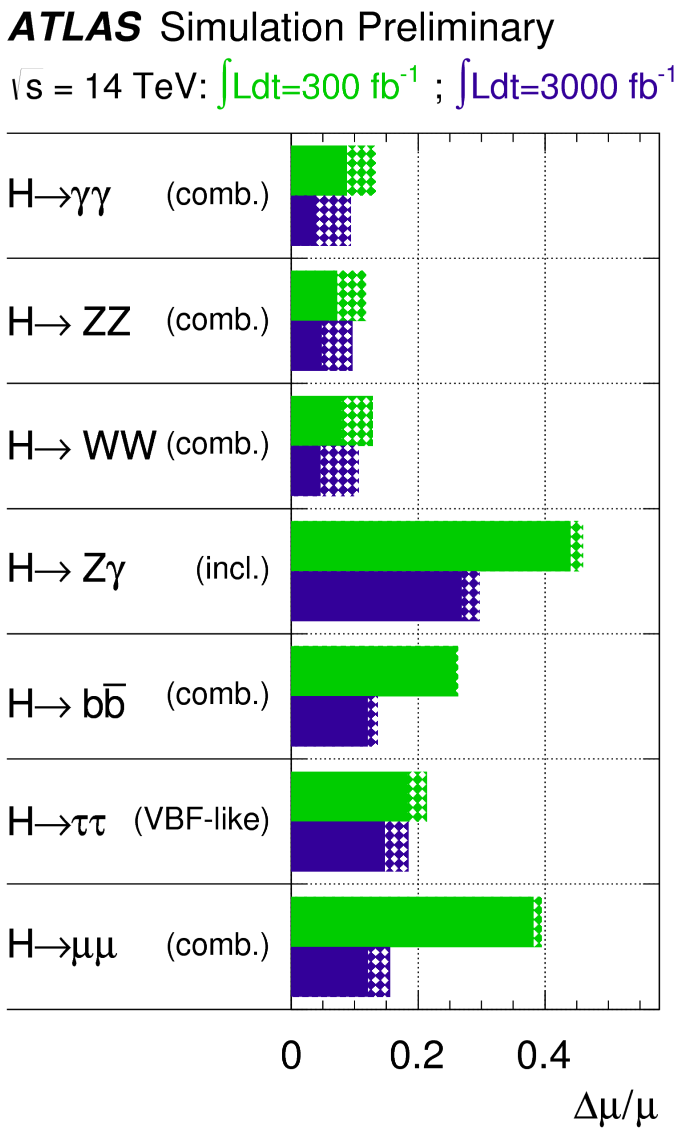
-> Physics targets : precision measurements /rare decays / beyond SM

- Longer latency for Trigger System
- Upgrade electronics for Tile Calorimeter
- Inner detector with fully Silicon (strip and pixel) **up to |η| = 4**
- New Inner Muon barrel trigger chambers
- Options for: - forward muon tagger
  - timing detectors



Higgs Couplings

- Extrapolation from Run-1 analysis at $<\mu_{PU}> = 140$ (**ATL-PHYS-PUB-2014-016**)



Run-1

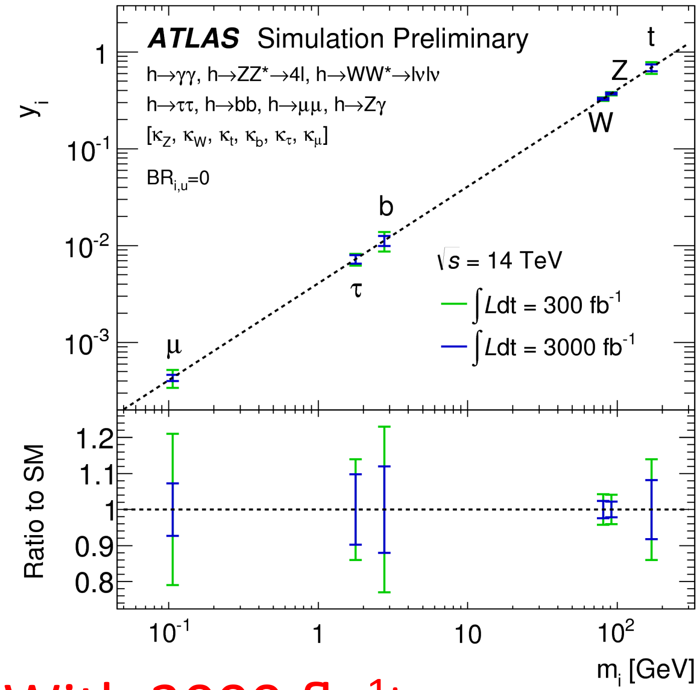
$\mu_{\gamma\gamma} = 1.17^{+0.28}_{-0.27}$ **($\Delta\mu/\mu \sim 0.23$)**

$\mu_{ZZ} = 1.46^{+0.40}_{-0.30}$ **($\Delta\mu/\mu \sim 0.24$)**

$\mu_{WW} = 1.18^{+0.42}_{-0.37}$ **($\Delta\mu/\mu \sim 0.33$)**

Signal Strength

$\mu = \sigma/\sigma_{SM}$

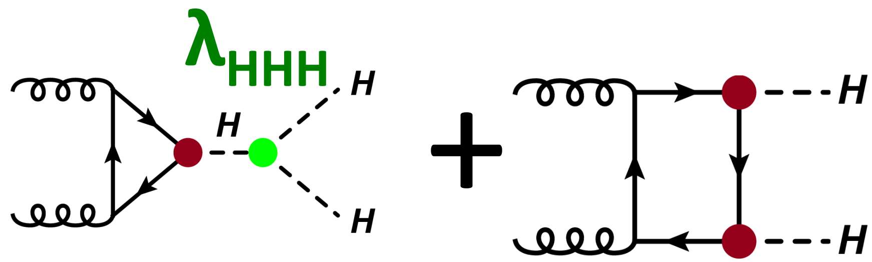


With 3000 fb^{-1}:

- ***W, Z*** couplings to 3%
- ***Muon*** coupling to 7%
- ***t,b,τ*** couplings to 8-12%

Higgs Self-coupling

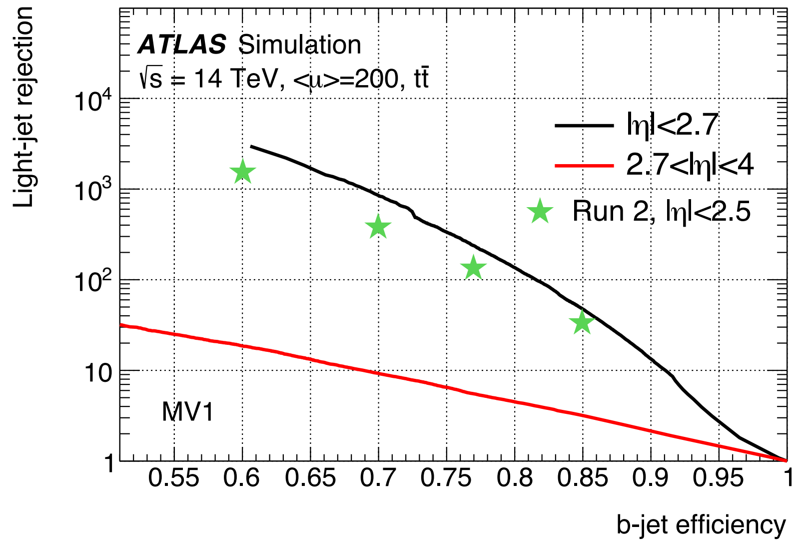
- First opportunity to measure Higgs boson trilinear self-coupling
- $\sigma_{NNLO}(HH)$ ~ 40 fb -> combine as many decay channels as possible



- Decay channels with b-jets have higher branching ratios

(ATL-TDR-025 LHCC-017-055)

Decay channel	Branching ratio (%)	σ.Br (fb)
$b\bar{b}+b\bar{b}$	33	12.9
$b\bar{b}+W^+W^-$	25	9.9
$b\bar{b}+\tau^+\tau^-$	7.4	2.9
$W^+W^-+\tau^+\tau^-$	5.4	2.1
$ZZ+b\bar{b}$	3.1	1.2
$ZZ+W^+W^-$	1.2	0.48
$b\bar{b}+\gamma\gamma$	0.3	0.12
$\gamma\gamma+\gamma\gamma$	0.001	0.04



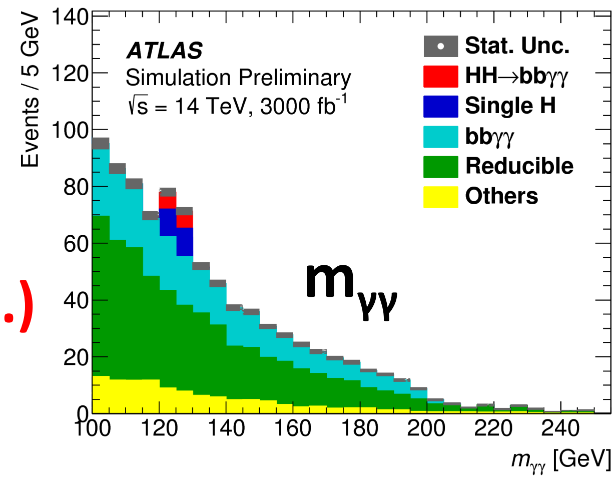
Comparable light jets rejection: with <μ> = 200 and Run-2

Higgs self-coupling

- **HH -> $b\bar{b}$ γγ**
  - Cut based analysis, ATLAS upgrade design y performance
  - SR: 9.5 signal, 91 total background

Z_0 : 1.05 σ (+/- 0.026 stat only)
$-0.8 < \lambda_{HHH}/\lambda_{SM} < 7.7$ (95% C.L. , no syst.)

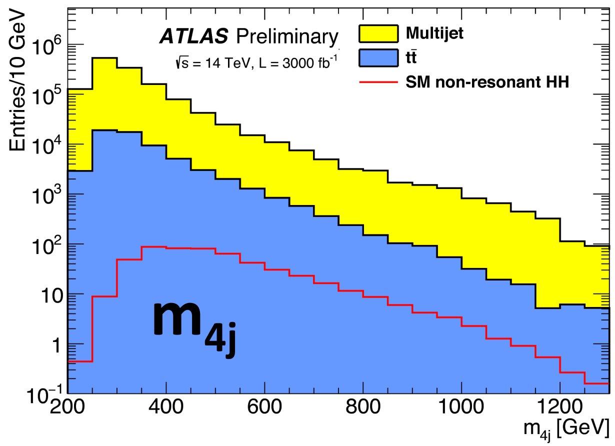
ATL-PHYS-PUB-2017-001



- **HH -> $b\bar{b}$ $b\bar{b}$**
  - Extrapolation from Run-2 analysis
  - Systematic as in 2016 (tt-bar, multi-jets bckg modeling)
  - Present exclusion limit : **$\mu = \sigma/\sigma_{SM} = 29$**

Jet Threshold [GeV]	Background Systematics	σ/σ_{SM} 95% Exclusion	$\lambda_{HHH}/\lambda_{HHH}^{SM}$ Lower Limit	$\lambda_{HHH}/\lambda_{HHH}^{SM}$ Upper Limit
30 GeV	Negligible	1.5	0.2	7
30 GeV	Current	5.2	-3.5	11
75 GeV	Negligible	2.0	-3.4	12
75 GeV	Current	11.5	-7.4	14

ATL-PHYS-PUB-2016-024



ttHH->WbWb bbbb
ATL-PHYS-PUB-2016-023

HH-> bb $\tau^- \tau^+$
ATL-PHYS-PUB-2015-046

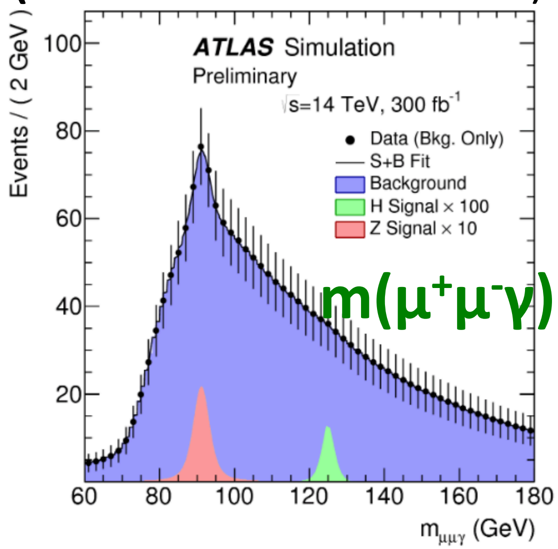
-> BACK-UP

Higgs rare decays

- **H -> J/Ψ (->μ⁺μ)⁻ γ** (with $<\mu_{PU}>$=140, L = 3000 fb^{-1})

(ATL-PHYS-PUB-2015-043)

  - Higgs coupling to c-quark. Run-1 detector performances
  - MVA analysis $m_{\mu+\mu-\gamma}$ in [115, 135] GeV
  - 3 signal events and 1700 background (with no systematics)



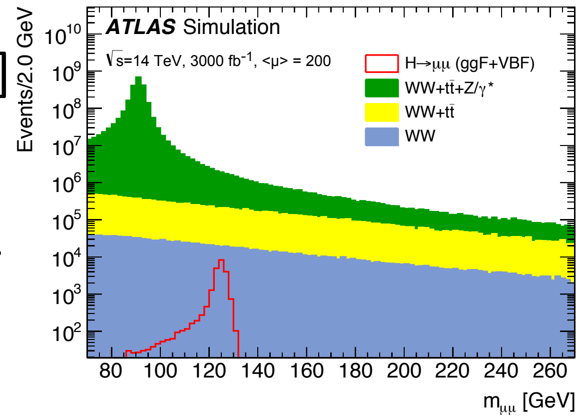
BR (H -> J/Ψ (->μμ) γ): 44^{+19}_{-22} x 10^{-6} (95% C.L.)

SM: 2.9 ±0.2 x 10^{-6} **(Run-1 Limit: 1.5 x 10^{-3})**

- **H -> $\mu^+ \mu^-$** (with $<\mu_{PU}>$=200, L = 300/3000 fb^{-1})

(ATL-TDR-025 LHCC-017-055)

- Low BR, high Z/γ^* background, high mass resolution
- Based on Run-1 analysis (cut optim.), $m_{\mu+\mu-}$ in [110, 160] GeV]
- Total background shape and normalization data-driven
- ITK-Upgrade -> improve **mass resolution by 25%** (w.r.t Run-2



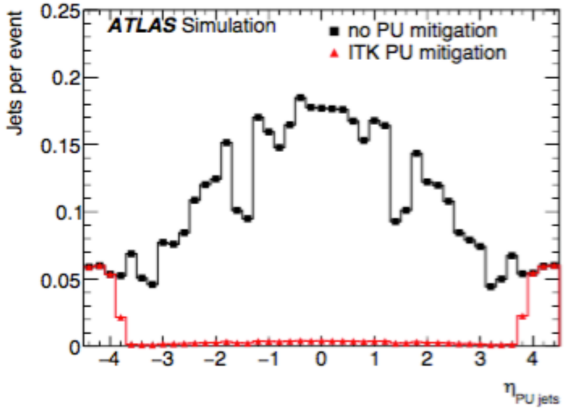
Z_0: 2.3σ (300 fb^{-1}) 7.0σ (3000 fb^{-1})

Δμ/μ: 46% (300 fb^{-1}) 21% (3000 fb^{-1})

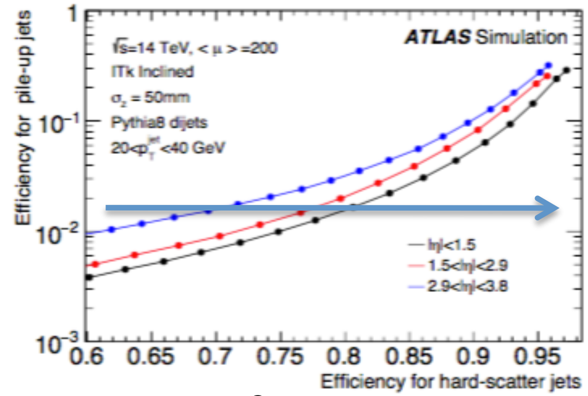
VBF Higgs production

(ATL-TDR-025 LHCC-017-055)

- Pile-up suppression:
  - **$\langle\mu_{PU}\rangle$ ~ 200 4.8 pu jets**/event
  - R_{PT} based on charge vertex fraction $$R_{p_T} = \frac{\sum_{\text{tracks}} p_T}{p_T(\text{jet})}$$
  - Applied to all non b-tagged jets with: p_T < 100 GeV and $|\eta|$<3.8



No PU mitigation
vs Pile-Up mitigation



Rejection factor 50
~0.2 pu jets/event

- **H -> WW* -> eν μν**
  - ATLAS performances: Run-1 (e/μ)
  - Jets and E_T^{Miss} from expected upgrade performance
  - Experimental systematic (no theo. syst. on signal)

Tracking coverage	σ(H ->WW*) Expected precision
$\|\eta\| < 4.0$	12%
$\|\eta\| < 3.2$	18%
$\|\eta\| < 2.7$	22%

- **H -> ZZ* -> 4l**
  - 2 jets(m(jj) > 130 GeV) ,
  - Main background ggF (separated via BDT) and qqZZ
  - Systematic only from signal QCD scale

	stat	stat+syst
Z_0 :	11.1	7.7
Δμ:	0.144	0.170

Supersymmetry Searches at HL-LHC

- Supersymmetry (SUSY) is one possible extension of the SM:
  - predicts bosonic/fermionic partner for existing fermion/bosons

-> lightest SUSY particle is stable (if R-parity conservation) -> DM candidate

-> Cancel out quadratic divergences in the Higgs mass corrections

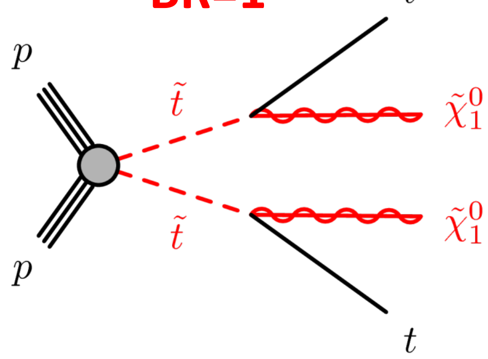
-> Can accommodate the gauge coupling unification

- Focus on HL-LHC benchmark studies:
  - 14 TeV, $\langle \mu_{PU} \rangle = 200$, total integrated luminosity of 3000 fb^{-1}
  - smearing function for upgraded ATLAS detector simulation
  - truth level particle corrected for detector effects
  - assume 30% systematic on background

Stop pair direct production

- Cut based analysis, top decaying leptonically
- Small mass splitting among stop and neutralino
  -> ISR jets to boost the stop-system
- Final state with 2b-jets, isolated leptons and E_T^{Miss}
- Profile-likelihood-ratio test statistics
  for expected exclusions
- Run-1 exclusion: $[m_t$, 191] U [230, 380] GeV

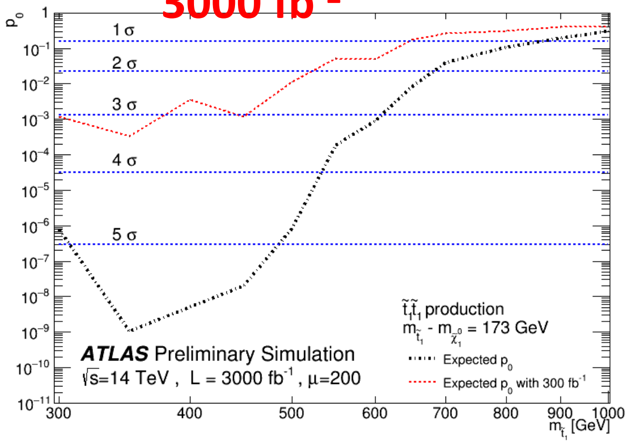
BR=1



$\Delta M(\tilde{t}, \tilde{\chi}^0_1)$ = 173 GeV

	SR
Expected Standard Model	13.8 ± 6.5
$t\bar{t}$	11.4 ± 5.1
$t\bar{t} + Z$	2.4 ± 1.5
Others	$0.0^{+1.8}_{-0.0}$
$\tilde{t}_1\,\tilde{t}_1\; m(\tilde{t}_1, \tilde{\chi}^0_1)$ = (350, 177) GeV	62.7 ± 7.5
$\tilde{t}_1\,\tilde{t}_1\; m(\tilde{t}_1, \tilde{\chi}^0_1)$ = (700, 527) GeV	11.0 ± 2.0

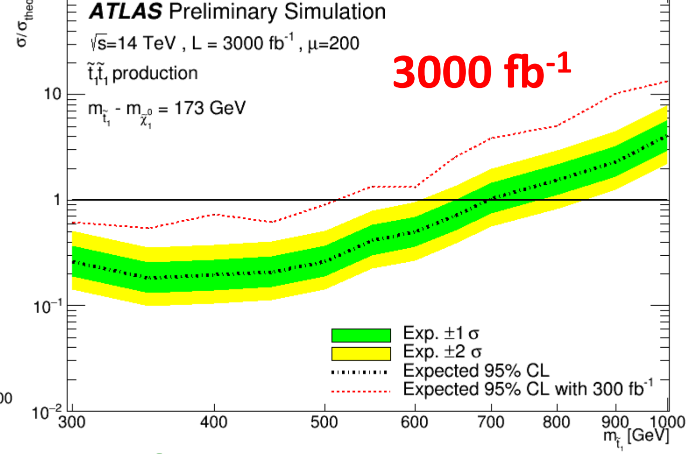
3000 fb^{-1}



Discovery up to 480 GeV

ATL-PHYS-PUB-2016-022

3000 fb^{-1}

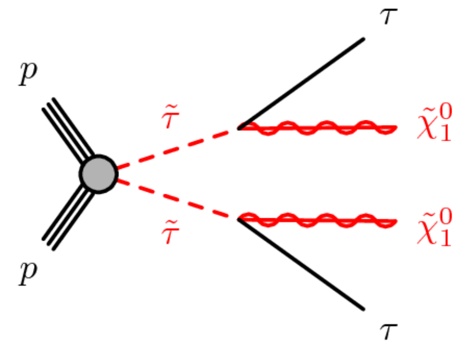


Exclusion up to 700 GeV

Stau pair direct production

- Extend the ATLAS exclusion scenario of combined $\tilde{\tau}_L\tilde{\tau}_L$ and $\tilde{\tau}_R\tilde{\tau}_R$ production with $\tilde{\chi}^0_1$ massless
- Cut based analysis: tau decaying hadronically, large E_T^{Miss}, low jet activity
- Main background: W+jets and tt-bar

For stau mass of 200 GeV:
$\sigma(\tilde{\tau}_L\tilde{\tau}_L)$ ~0.02 pb $\sigma(\tilde{\tau}_R\tilde{\tau}_R)$ ~0.01 pb



5σ discovery sensitivity ($\tilde{\chi}^0_1$ massless):

—— **100-500** GeV in $\tilde{\tau}$-mass for ($\tilde{\tau}_L\tilde{\tau}_L$ and $\tilde{\tau}_R\tilde{\tau}_R$) combined production

—— **120-430** GeV for pure $\tilde{\tau}_L\tilde{\tau}_L$

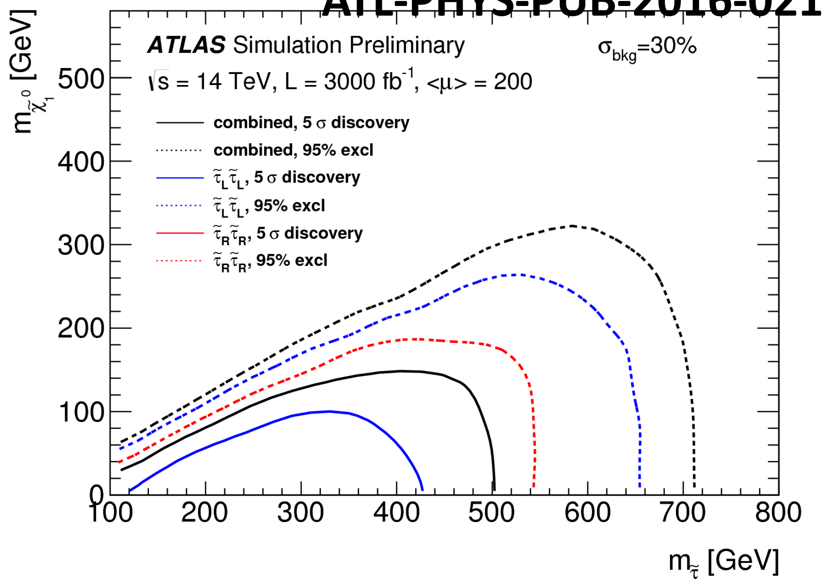
Exclusion limit ($\tilde{\chi}^0_1$ massless):

---- **700** GeV in $\tilde{\tau}$-mass for ($\tilde{\tau}_L\tilde{\tau}_L$ and $\tilde{\tau}_R\tilde{\tau}_R$) combined production

----- **650** GeV for pure $\tilde{\tau}_L\tilde{\tau}_L$

----- **540** GeV for pure $\tilde{\tau}_R\tilde{\tau}_R$ (**Run-1: 109 GeV**)

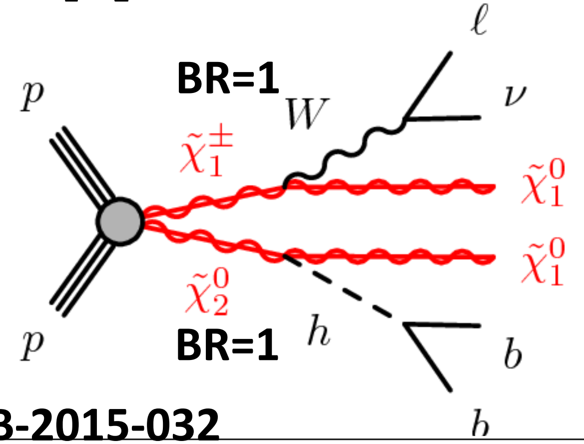
ATL-PHYS-PUB-2016-021



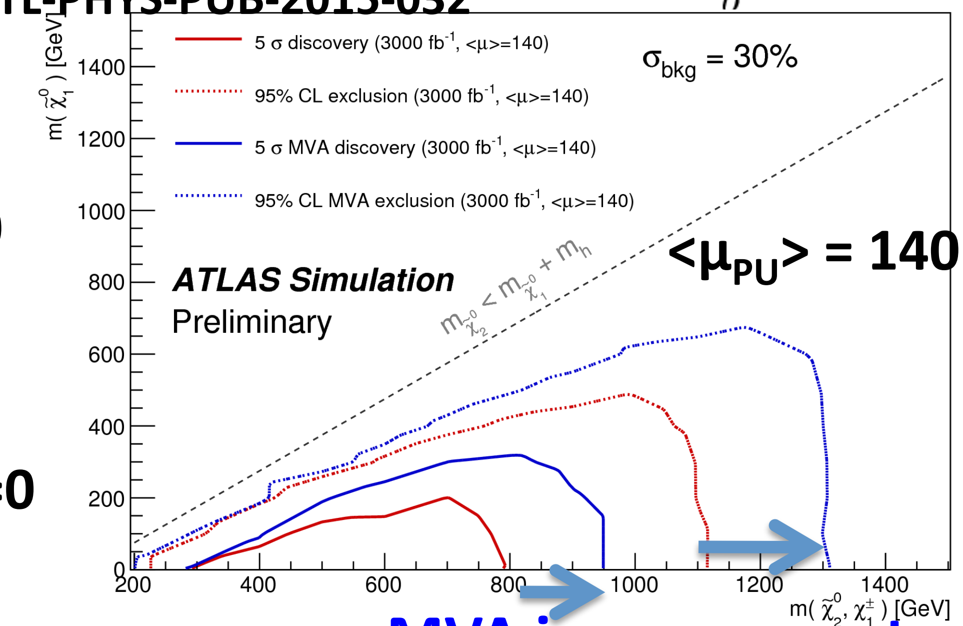
Direct chargino and neutralino production

- Extend the present ATLAS sensitivity to electro-weakinos mass range O(100 GeV)
- Simplified model:
  - $\tilde{\chi}^{\pm}_1 \tilde{\chi}_2^0$ are wino-like and with equal mass
  - sleptons and sneutrino with high mass, SM Higgs
- Cut based and MVA analysis
- Main background: tt-bar

$\sigma^{NLO}(\tilde{\chi}^{\pm}_1 \tilde{\chi}_2^0)$ ~0.005 pb (@ 500GeV)



ATL-PHYS-PUB-2015-032



MVA improvement

5σ discovery sensitivity :

— **950 GeV** in mass $\tilde{\chi}^{\pm}_1 \tilde{\chi}_2^0$ for $m(\tilde{\chi}_1^0) = 0$

Exclusion limit:

---- 1310 GeV in mass $\tilde{\chi}^{\pm}_1 \tilde{\chi}_2^0$ for $m(\tilde{\chi}_1^0) = 0$

Conclusions

- HL-LHC will represent a **challenging environment** for ATLAS:

  -> $<\mu_{PU}>$ = 200 , large backgrounds , high radiation dose

- **Higgs and SUSY physics** program will **benefit greatly** from HL-LHC data and ATLAS Phase II Upgrade

  -> Can explore the ***HH*** production mechanism

  -> Precise measurements of Higgs couplings

  -> Can extend the present sensitivities to heavy SUSY particles greatly

- The current expected ATLAS **precisions** at HL-LHC are still preliminary

  -> Better analysis techniques, better data-driven methods for background

  -> Theoretical uncertainties expected to decrease with time

BACK UP

Summary of Higgs results at HL-LHC

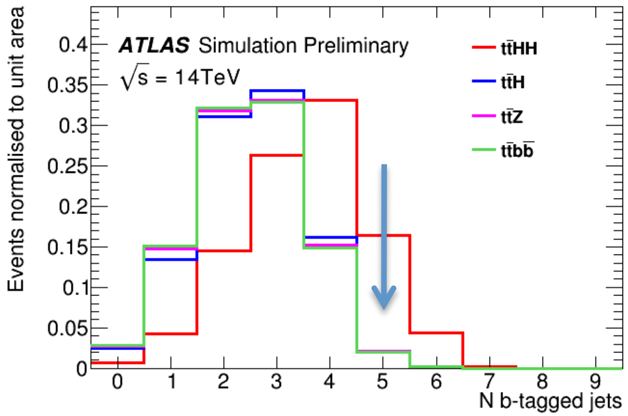
Channels	Result	HH final State	Significance Coupling limit
VBF H->WW*	**$\Delta\mu/\mu \simeq$ 14 to 20%**	HH → $b\bar{b}\ \gamma\gamma$ (stat)	**1.05 σ** **$-0.8 < \lambda_{HHH}/\lambda_{SM} < 7.7$**
VBF H->ZZ*	**$\Delta\mu/\mu \simeq$ 15 to 18%**	HH → $b\bar{b}\ \tau^+\tau^-$ (stat+syst)	**0.6 σ** **$-4.0 < \lambda_{HHH}/\lambda_{SM} < 12.0$**
ttH, H->γγ	**$\Delta\mu/\mu \simeq$ 17 to 20%**	HH -> bbbb (stat+syst)	**--** **$-3.5 < \lambda_{HHH}/\lambda_{SM} < 11.0$**
VH, H→γγ	**$\Delta\mu/\mu$~ 25 to 35%**	ttHH, HH → $b\bar{b}b\bar{b}$	**0.35 σ** **--**
H-> Zγ	**$\Delta\mu/\mu$ ~ 30%**	*H→ZZ*→4l* (m(4l)>220 GeV)	**$\Gamma_H = 4.2^{+1.5}_{-2.1}$ MeV** **(stat.+syst.)** Run-1: $\Gamma_H < 22.7$ MeV
H->$\mu^+\mu^-$	**$\Delta\mu/\mu$ ~ 15%**		
H-> J/ψ γ	**BR < 44 x 10^{-6} @ 95 % C.L.**		**ATL-PHYS-PUB-2015-024**

Higgs self-coupling: 3000 fb^{-1}

- **$t\bar{t}HH \to WbWb\ b\bar{b}b\bar{b}$ with $\langle\mu_{PU}\rangle = 200$**
  - $\sigma(t\bar{t}HH) \sim 1$ fb
  - Cut based analysis, Final State: $HH \to b\bar{b}b\bar{b}\ t\bar{t} \to b\bar{b}l\nu qq$
  - Signal Region (≥5 b jets): 25 signal, 7100 background (dominated by c-jets mis-tagged as b-jets)

Significance: ~ 0.35 σ (no systematics)
-> small contribution

ATL-PHYS-PUB-2016-023



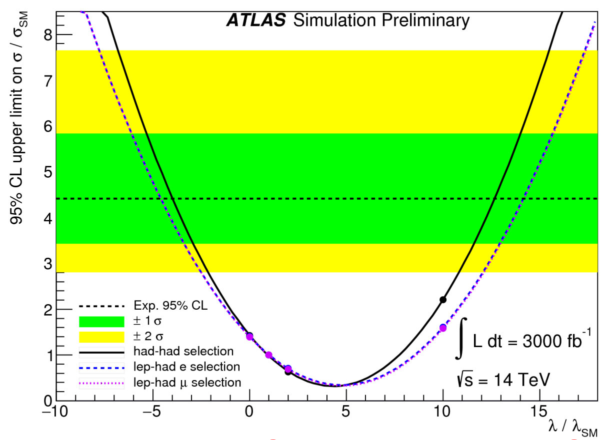
- **$HH \to b\bar{b}\ \tau^-\tau^+$ with $\langle\mu_{PU}\rangle = 140$**
- Different triggers/cuts for $\tau_{had}\tau_{hah}$ resp. $\tau_{had}\tau_{lep}$ channels
- Constraint on $m(b\bar{b})$ and $m(\tau\tau)$
- Systematic: 2% lumi., 3% for major bckg (Z+jets, tt-bar)
- Combined channels yields: Signal: 48 Bckg.: 7810

Significance: ~ 0.60 σ (with syst.)

$-4 < \lambda_{HHH}/\lambda_{SM} < 12$ (95% C.L. with syst)

ATL-PHYS-PUB-2015-046

σ / σ_{SM} as a function of λ / λ_{SM}



$4.3 \times \sigma(HH \to bb\tau^-\tau^+)$ (95% C.L.)

ATLAS HL-LHC Analysis Strategy

- Two approaches to study the HL-LHC physics performance with ATLAS

Use of smearing functions:

- Study detector performances for phys. objects (e,mu,..) with full MC simulations
- Apply 'smearing functions' to truth distributions for analysis, overlay PU jets

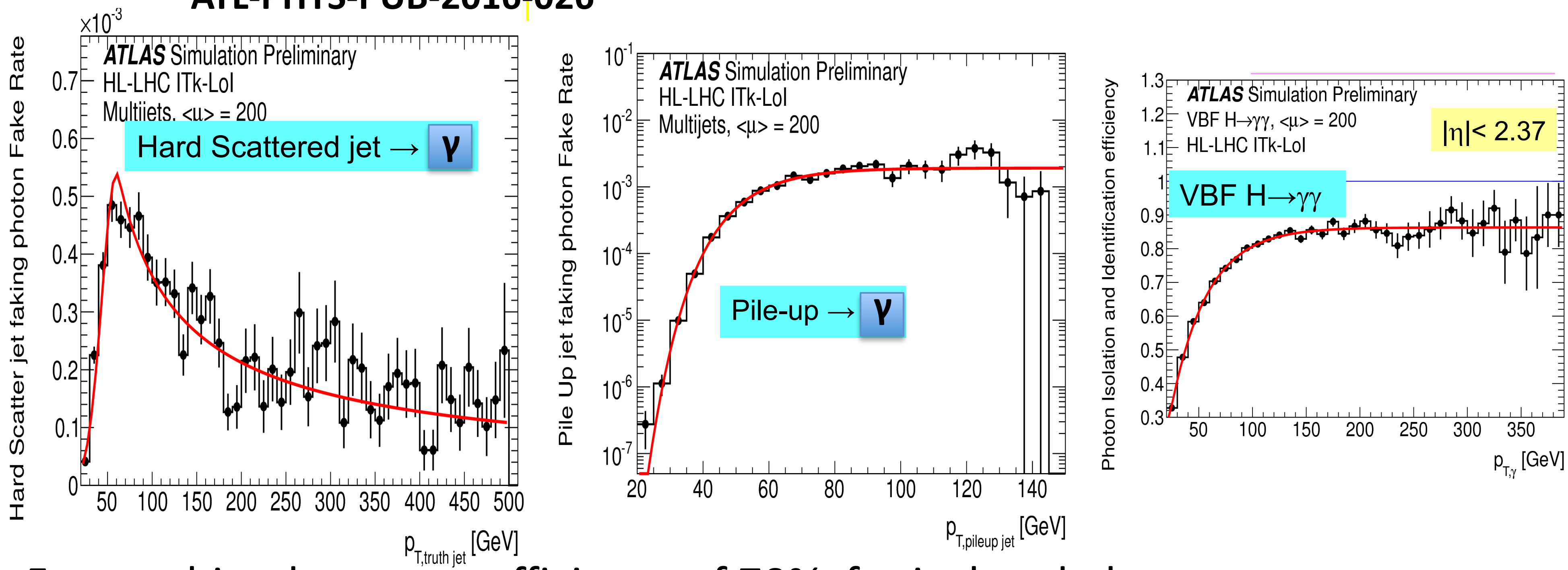
Extrapolation of Run-1/Run-2 results

- similar detector performance and analysis approach as Run-1/Run-2
- Scale signal and background level to higher luminosity, c.o.m. energy

- Systematics (will have ~x10 more higgs at HL-LHC than at the end of Run-2)
  - Theoretical: from Run1/Run2
  - Experimental: scaled to best guess for ATLAS upgraded detector at HL-LHC

Pile-up II: Photons

ATL-PHYS-PUB-2016-026



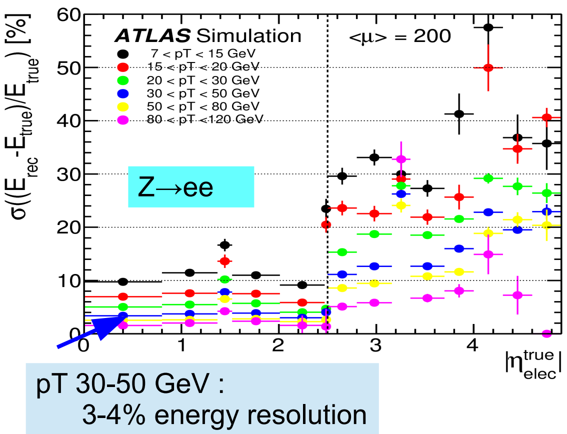
- For combined average efficiency of 70% for isolated photons:

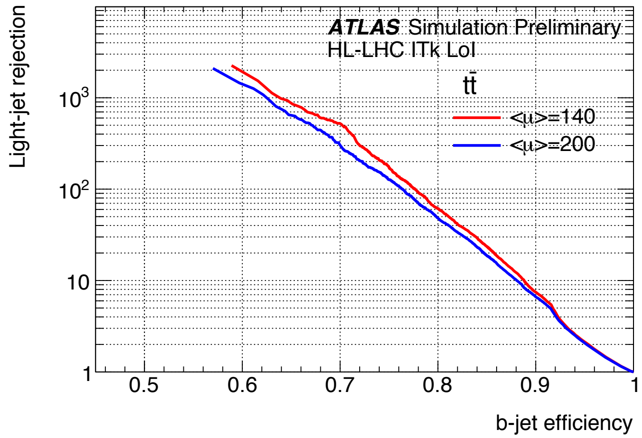
- Rejection factor of ~4000 for hard-scattered jets

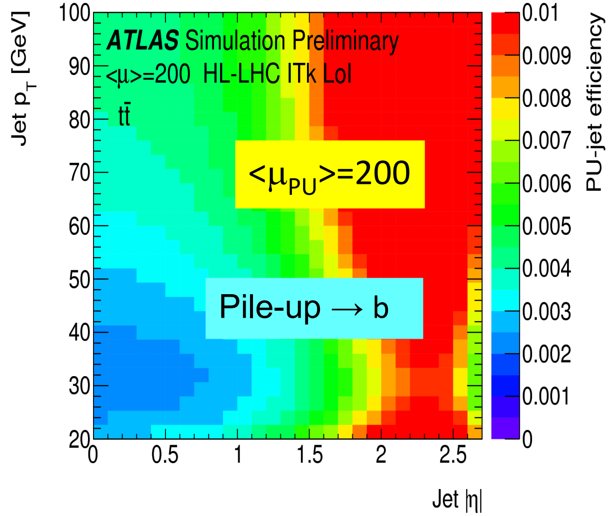
- Rejection factor of ~14000 for pile-up jets

ATLAS Upgrade Performances

ATL-PHYS-PUB-2016-026







- For an electron identification efficiency of 69%, a jet rejection factor of about 4000 is obtained. Also, an electron charge mis-identification of about 0.26% has been evaluated for the first time

- For 70% b-jet efficiency (with MV1 tagger):

 - light jet rejection of ~380 with <mu> = 200 (best optimized Run-2 b-tagger has 380 at 70% eff.)

- Muon with Pt < 200 GeV greatly benenfit from Itk momentum resolution

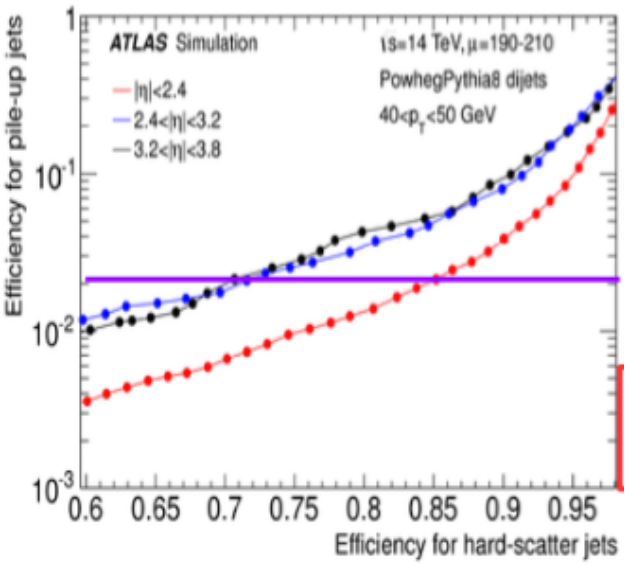
 - B_s^0 mass resolution in the $B_s^0 \rightarrow \mu+ \mu-$ will improve by a factor of about 1.65 (1.5) in the barrel (end-cap) region

Pile-up suppression

- Typical jet selections require ***pT* (jet) >30 GeV, |η(jet)| < 3.8**
- With <μ_{PU}> = 200 expected 4.8 pileup jets with ***pT* >30 GeV, |η|<3.8** per event
- Pile-up suppression with a **parametrized track-confirmation requirement**

$$R_{p_T} = \frac{\sum_{\text{tracks}} p_T}{p_T(\text{jet})}$$

- Applied to all non ***b***-tagged jets with ***pT* < 100 GeV** and **|η|<3.8**



CERNLHCC-2015-020

Analyses typically use factor 50 rejection

-> ~0.2 pile-up jet per event

-> 85-70 % efficiency on hard-scatter jets

ATLAS ITK Mass Resolution

(ATL-TDR-025 LHCC-017-055)

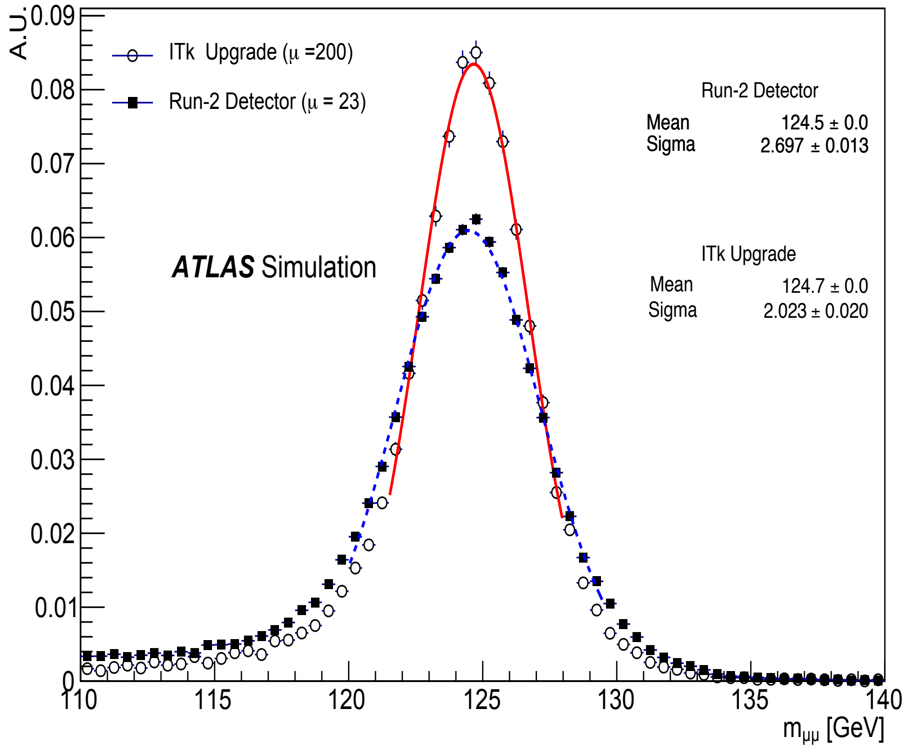
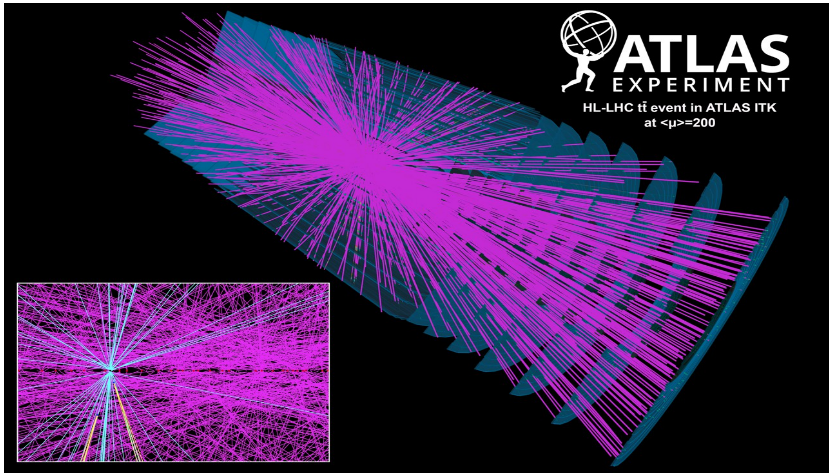


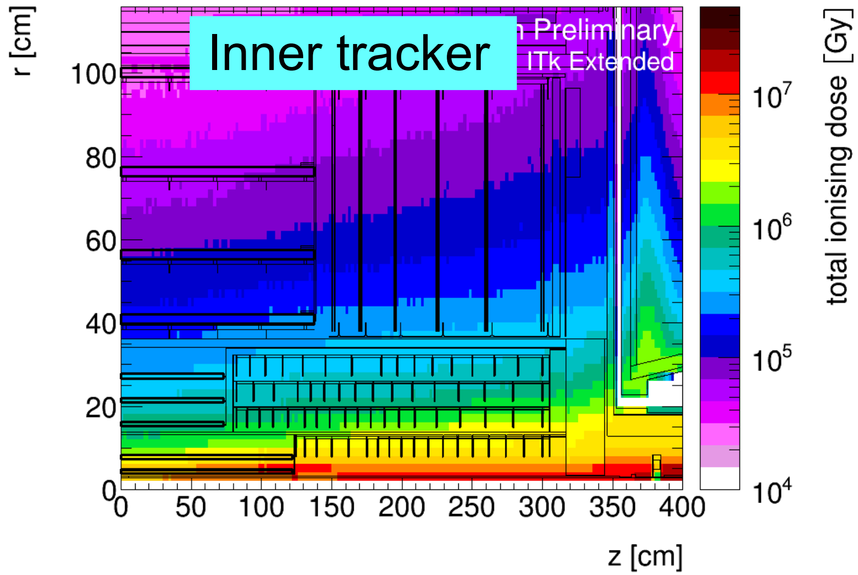
Figure 4.38: Signal resolution for $H \to \mu\mu$ signal events, the Run 2 resolution is compared to the HL-LHC with pile-up conditions corresponding to $\langle \mu \rangle = 200$.

ATLAS Running Conditions

High particle density



High integrated radiation dose



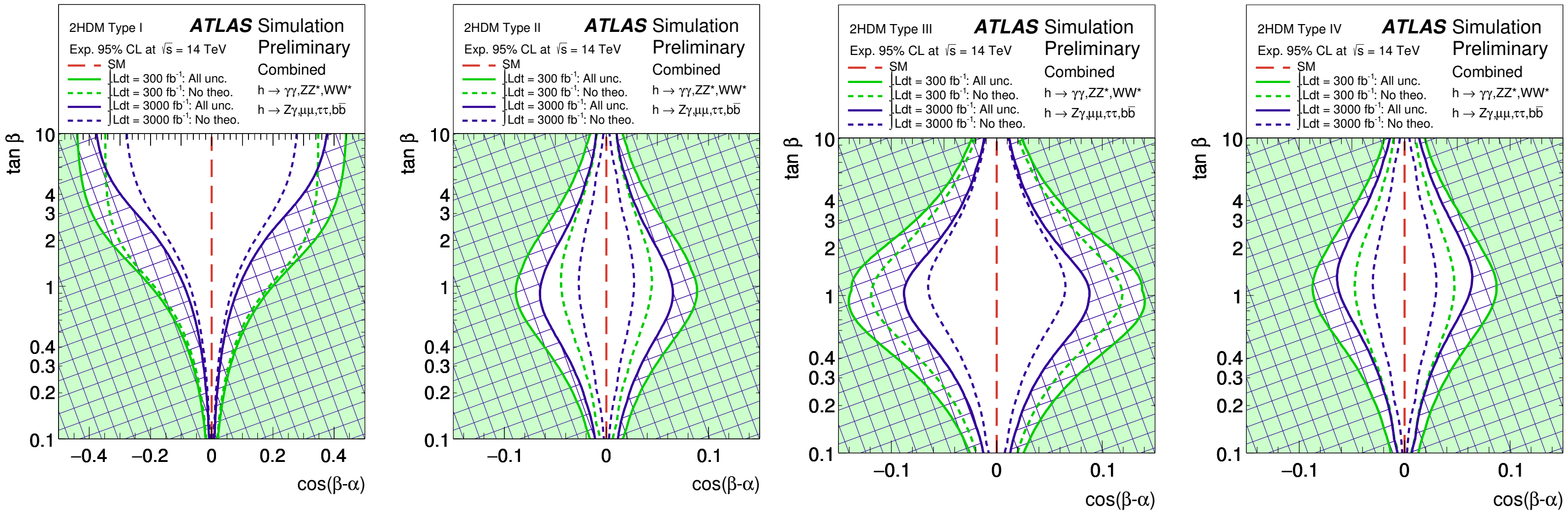
Detector requirements to maximize benefits from high int. luminosity:

- Replace detector not sustaining integrated radiation dose
- Minimize pile-up effect (high granularity, fast timing)
- Higher trigger acceptance and event rate
- Improve or maintain current detector performances

Higgs BSM constraints

ATL-PHYS-PUB-2014-016
ATL-PHYS-PUB-2014-017

300, 3000 fb^{-1}
$\langle\mu_{PU}\rangle = 140$



(a) Type I (b) Type II (c) Type III (d) Type IV

Figure 4: Regions of the ($\cos(\beta-\alpha)$, $\tan\beta$) plane of four types of 2HDMs expected to be excluded by fits to the measured rates of Higgs boson production and decays. The confidence intervals account for a possible relative sign between different couplings. The expected likelihood contours where $-2\ln\Lambda = 6.0$, corresponding approximately to 95% CL (2σ), are indicated assuming the SM Higgs sector. The light shaded and hashed regions indicate the expected exclusions.

Analysis Techniques

ATLAS HL-LHC studies have to consider:

- upgraded ATLAS detector + trigger systems
- collision energy, $\sqrt{s} = 14$ TeV
- high pile-up, $\langle\mu_{PU}\rangle$, of 140 or 200

- We use **generator-level** $\sqrt{s} = 14$ TeV Monte Carlo samples
- Overlay with jets from dedicated ***pile-up library***
  - ➡ **pile-up library** contains fully simulated pile-up jets with $\langle\mu_{PU}\rangle = 140$ or 200
- Reconstruct electron, muons, jets, photons and missing-E_T from generator+overlay information

- To simulate the response of the detector:
  - ➡ smear p_T and energy of reconstructed physics objects using ***smearing functions***
  - ➡ apply **reconstruction efficiencies** for electrons, muons and jets

- To emulate triggers: apply **trigger efficiency** functions

- Smearing and efficiency functions determined from fully-simulated samples using ATLAS HL-LHC detector and high pile-up
  - ➡ Functions are dependent on p_T and η

- Most analysis presented use single lepton or di-lepton triggers (e, μ)
  - ➡ di-τ triggers and 4-jet triggers used for particular analyses

- Parametrised b-tagging (based on ATLAS Run 1 `MV1` tagger) is performed on reconstructed jets

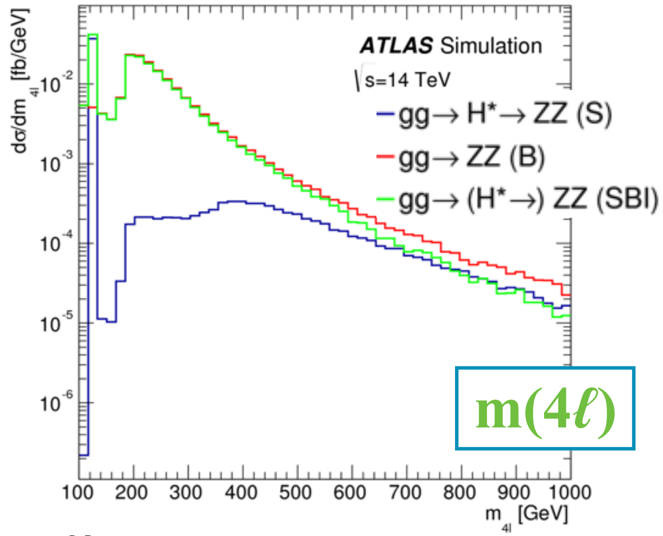
- This approach to ATLAS HL-LHC prospects studies has been validated on a limited number of physics studies comparing full simulation and the *generator-level+smearing* technique

Higgs Width at HL-LHC

Measure off-shell production of $H \rightarrow ZZ^* \rightarrow 4\ell$ with **m(4ℓ)>220 GeV**

Use **m(4ℓ)** shape and matrix element to discriminate between signal and background

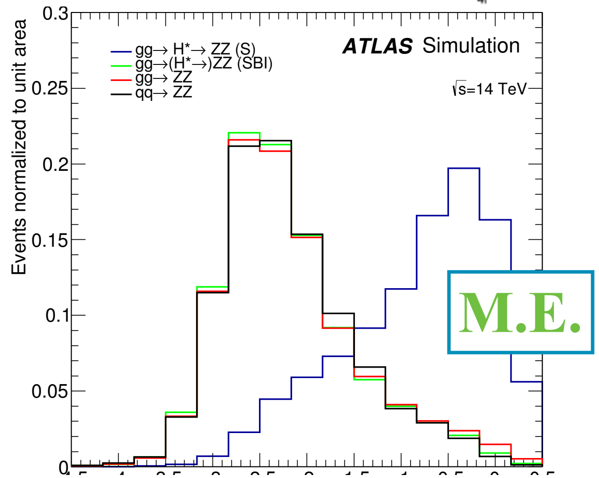
- ➡stat. uncertainties only: $\mu_{\text{off-shell}}=1.00^{+0.23}_{-0.27}$
- ➡stat.+syst. uncertainties: $\mu_{\text{off-shell}}=1.00^{+0.43}_{-0.50}$



- Off-shell production used to constrain the Higgs boson width Γ_H

- For $\Gamma = \Gamma_{SM}$ combining with on-shell measurement, (assuming off-shell measurement dominates):

$\Gamma_H = 4.2^{+1.5}_{-2.1}$ MeV (stat+sys)



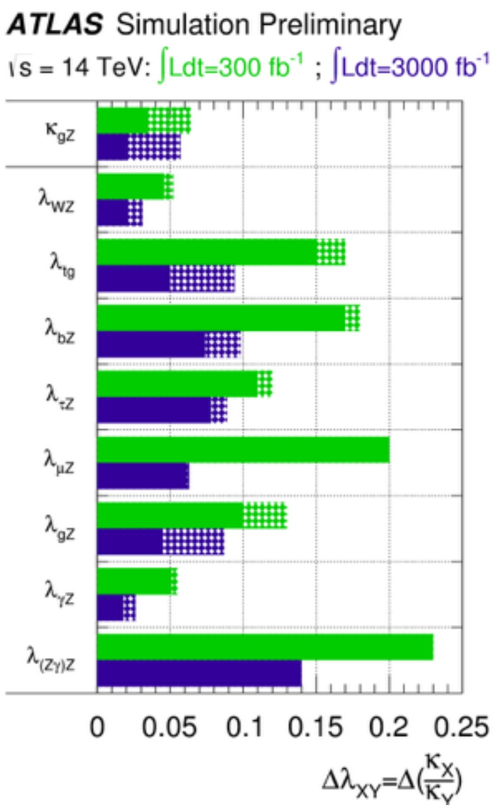
- Run 1 limit: $\Gamma_H <$ 22.7 MeV at 95% CL (*WW, ZZ*)

Higgs coupling K-Framework

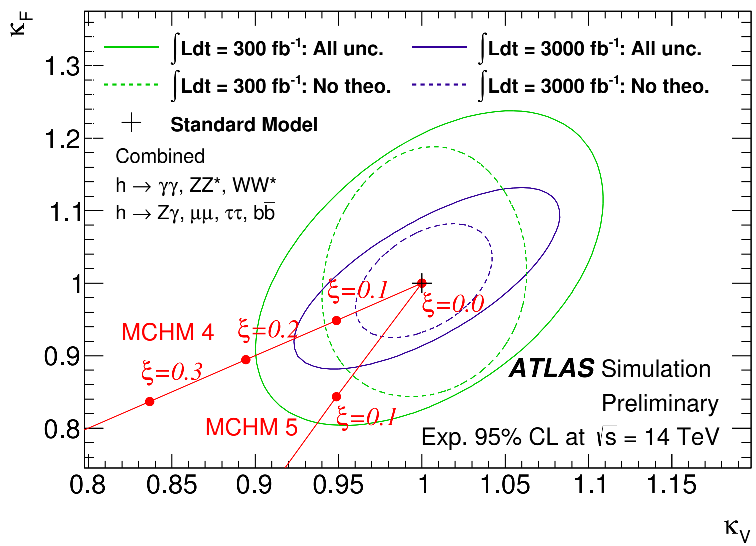
ATL-PHYS-PUB-2014-016

- Assuming Γ_H is sum of SM widths, calculate uncertainties on Higgs boson couplings.
- Deviations from the SM are quantified using κ multiplier, in SM $\kappa_i = 1$, *e.g.*:

$$(\sigma \cdot \mathrm{BR})(gg \to H \to \gamma\gamma) = \sigma_{\mathrm{SM}}(gg \to H) \cdot \mathrm{BR}_{\mathrm{SM}}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$



- Assume universal modifications to Higgs couplings to fermions (κ_F) and vector bosons (κ_V)



ATLAS HL-LHC Analysis Strategy

- Detector performance of different physics objects (e, μ, γ,…) with MC (Full Sim.)
- Parametrization to provide 'smeared truth' simulation to benchmark analysis
- Jets from pile-up events are overlaid on the hard-scatter events
- Signals from interactions in previous bunch crossings are added (calorimeter response)

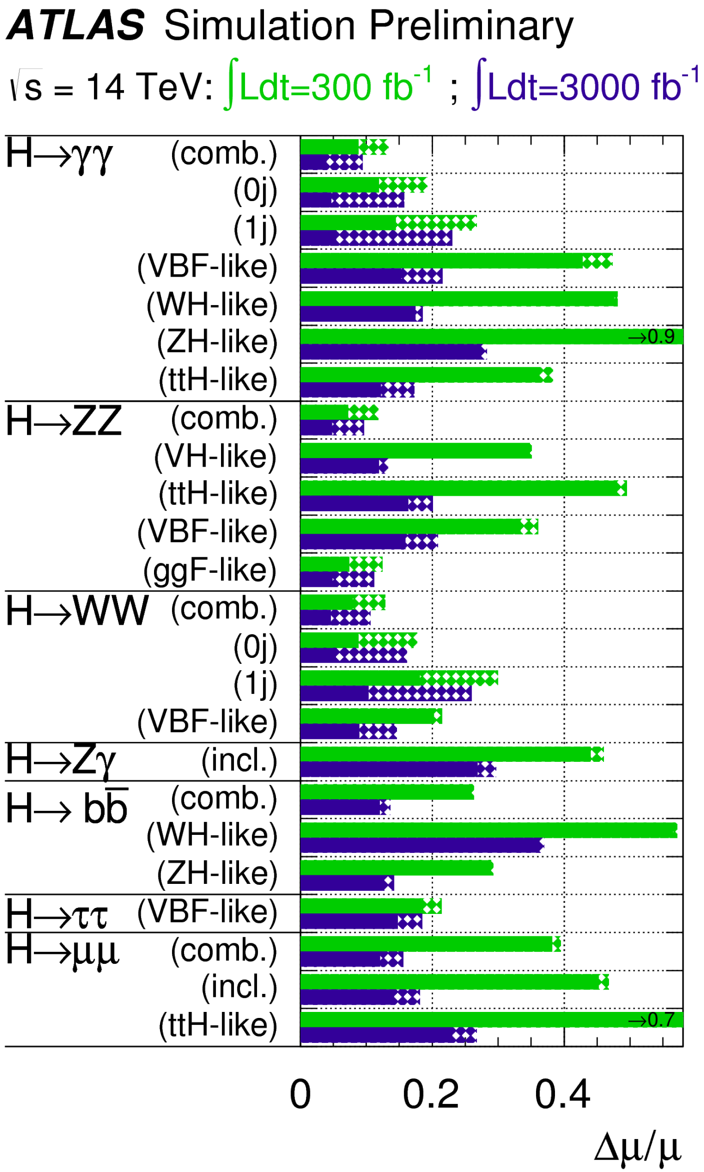
Extrapolation of Run-1/Run-2 results

- similar detector performance and analysis approach as Run-1/Run-2
- Scale signal and background level to higher luminosity, c.o.m. energy

Detector system	Trigger–DAQ		Inner Tracker	Inner Tracker + Muon Spectrometer	Inner Tracker + Calorimeter		
Physics Process \ Object Performance	Efficiency/ Thresholds $\mu^\pm$	Efficiency/ Thresholds $e^\pm$	b-tagging	$\mu^\pm$ Identification/ Resolution	Pile-up rejection	Jets	E_T^{miss}
$H \longrightarrow 4\mu$	✓			✓			
VBF $H \to ZZ^{(*)} \to \ell\ell\ell\ell$	✓	✓		✓	✓	✓	
VBF $H \to WW^{(*)} \to \ell\nu\ell\nu$	✓	✓	✓	✓	✓	✓	✓
SM VBS ssWW	✓	✓		✓	✓	✓	✓
SUSY, $\chi_1^\pm \chi_2^0 \to \ell b\bar{b} + X$	✓	✓	✓	✓	✓	✓	✓
BSM $HH \to b\bar{b}b\bar{b}$			✓			✓	

- Systematics (will have ~x10 more higgs at HL-LHC than at the end of Run-2)
  - Theoretical: from Run1/Run2
  - Experimental: scaled to best guess for ATLAS upgraded detector at HL-LHC
- Pile-up suppression (~factor 50) track-confirmation requirement (~0.2 p.u. jets/event)

Higgs Couplings



Run-1

$\mu = 1.17^{+0.28}_{-0.27}$

($\Delta\mu/\mu \sim 0.23$)

$\mu = 1.46^{+0.40}_{-0.30}$

($\Delta\mu/\mu \sim 0.24$)

$\mu = 1.18^{+0.42}_{-0.37}$

($\Delta\mu/\mu \sim 0.33$)

- Extrapolation from
- Run-1 analysis at $\langle\mu_{PU}\rangle = 140$
- (**ATL-PHYS-PUB-2014-016**)

With 3000 fb^{-1}:

- ***W, Z*** couplings to 3%
- ***Muon*** coupling to 7%
- ***t,b,τ*** couplings to 8-12%