Physics prospects of the high luminosity LHC with the ATLAS detector

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LHC High-Luminosity Prospects OUTLOOK

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HL-LHC

HL-LHC PLANS

CONDITIONS & UPGRADE STATUS & MOTIVATION

SM HIGGS COUPLINGS

BSM PHYSICS IN HIGGS COUPLINGS

HIGGS PAIR PRODUCTION

SUSY

CONCLUSIONS

LHC High-Luminosity Plans HL-LHC

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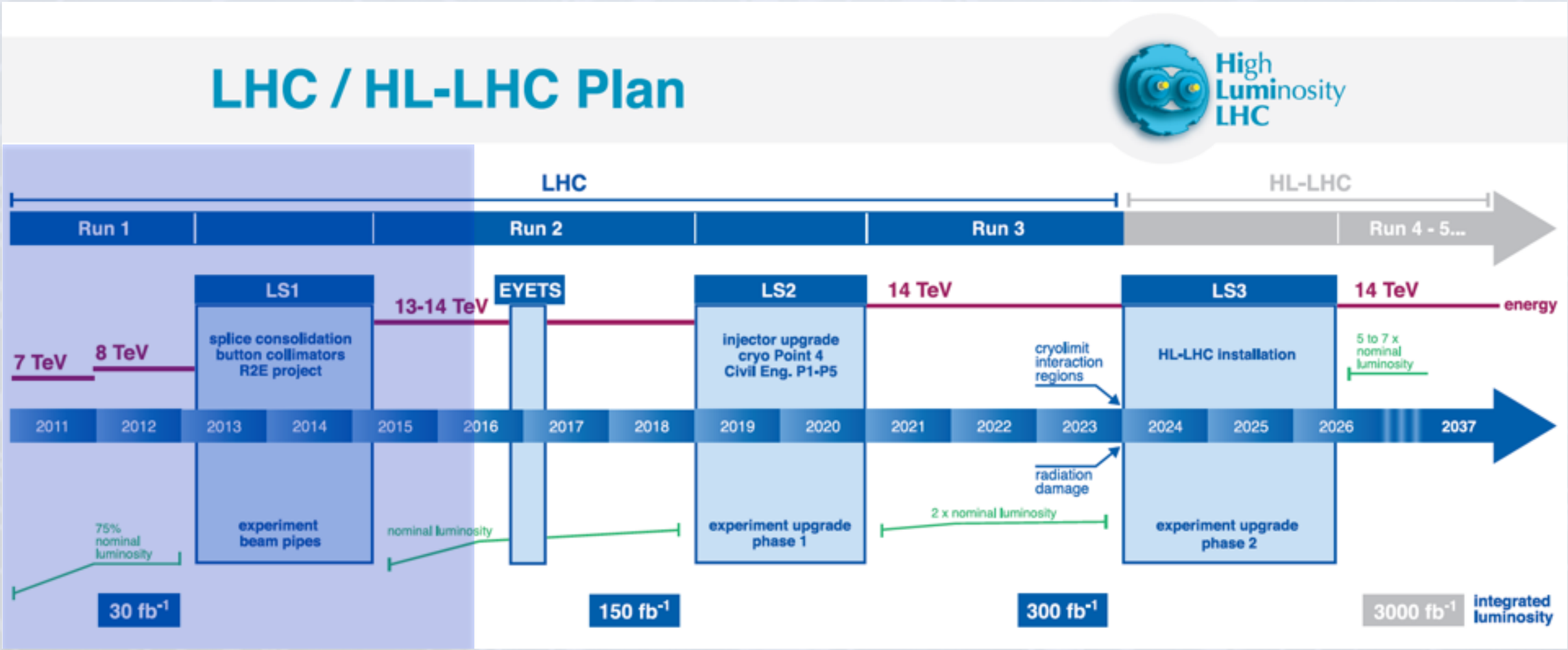


Run1: -> Higgs discovery

Run2: -> Design energy & lumi

Run3: -> 2x Design luminosity

HL-LHC: -> 10x Design luminosity

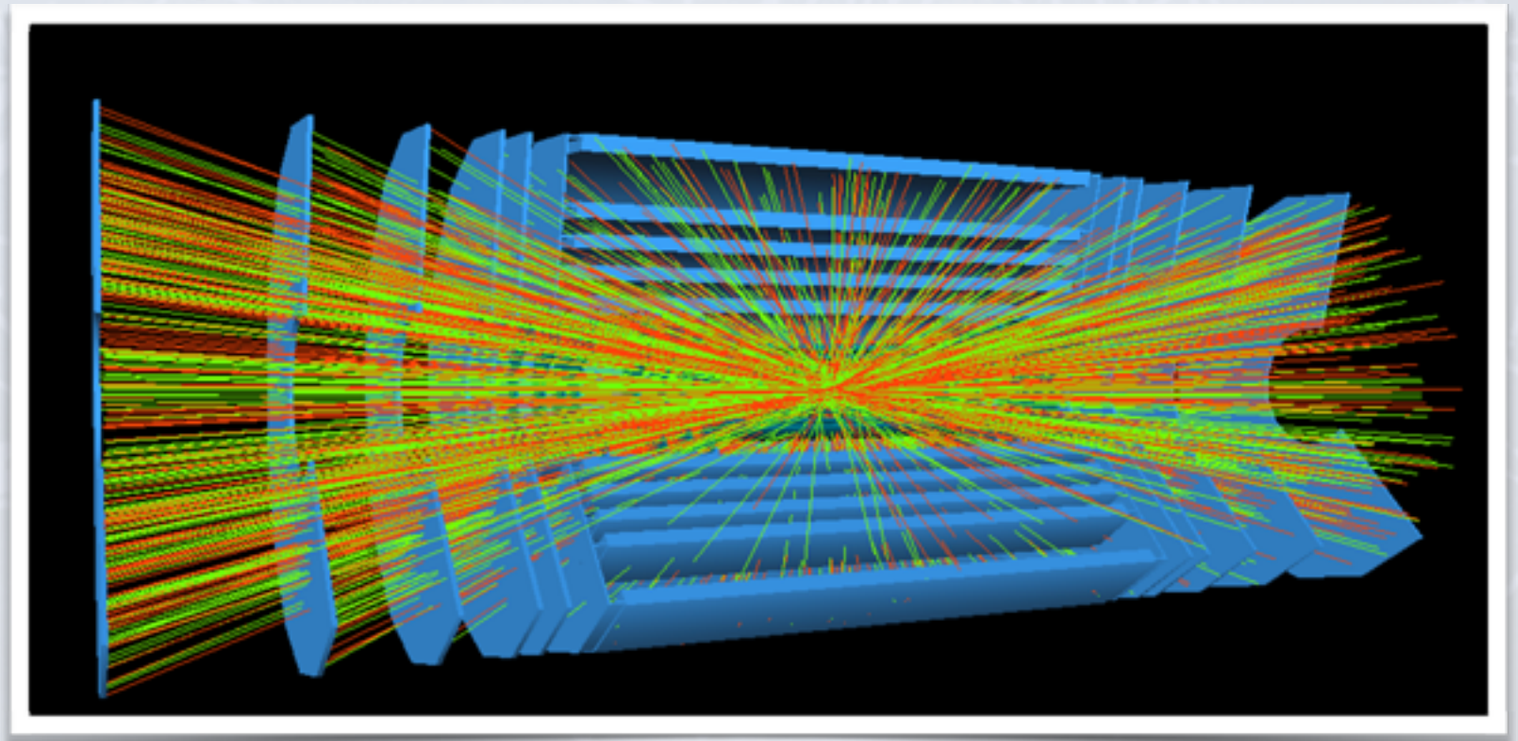
LS1: Magnet splice update

LS2: Injectors

LS3: IP focusing

LHC High-Luminosity Conditions HL-LHC

- 14 TeV centre of mass energy
- 5 (7.5) x $10^{34}cm^{-2}s^{-1}$ nominal (ultimate) inst. luminosity
- 40 MHz maximal bunch crossing rate
- Pile-up μ = 140 (200) p-p interactions per bunch crossing
- 3000 fb^{-1} in order ten years



SIMULATED ATLAS INNER DETECTOR EVENT WITH 230 PILEUP

LHC High-Luminosity Status HL-LHC

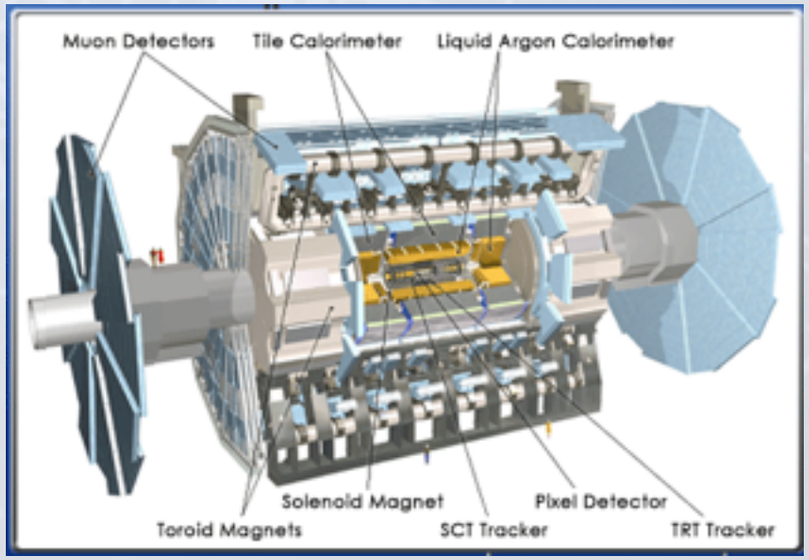
European Strategy 2012: "Europe's top priority should be the exploitation of the full potential of the LHC, including the high luminosity upgrade of the machine and the detectors with a view to collecting 10 times more data than in the initial design, by around 2030"

European Strategy for Particle Physics

- Phase II LoI [CERN-LHCC-2012-022] - detector upgrade
- ECFA HL-LHC workshop 2014
- Scoping Document [CERN-LHCC-2015-020] - cost scenarios vs. physics performance
- Public results: UpgradePhysicsStudies
- Most simulations are using $\mu = 140$ and not yet using full Inner Detector coverage of 4.0 pseudo rapidity

ATLAS Experiment Upgrades HL-LHC

- **Trigger and Data Acquisition**
  - Hardware trigger with L0 ≤ 1MHz and L1 ≤ 400 KHz
  - High-Level Trigger with 10 kHz output (permanently recorded data)
  - "Custom hardware" triggers for data streaming at rates 1-40 MHz
  - New Inner Tracker, Calorimeters and Muon Triggers
- **Calorimeters**
  - LAr forward electromag. calorimeter replaced with high-granularity
  - High Granularity Timing Detector installed in front of LAr Cal end-caps, $2.4 \leq |\eta| \leq 4.3$
  - Readout electronics of LAr and Tile Calorimeters replaced
- **Muon Spectrometer**
  - NSW in the end-cap at Phase1
  - Addition of RPCs in the barrel, $|\eta| < 1$
- **Inner Tracker**
  - Completely new, all-silicon tracker
  - Extending coverage to $|\eta| < 4$



Physics Motivation HL-LHC

- EWSB Understanding:
  - Precise 125 GeV Higgs couplings to bosons & fermions
  - Precise Yukawa couplings measurements (especially direct top Yukawa coupling), search for rare Higgs decays
  - HH production studies: aim to estimate Higgs potential (self-coupling λ_{hhh}), the ultimate test for SM EWSB
  - Testing vector-boson scattering probes composite nature of the Higgs

- BSM Physics couplings to Higgs, direct searches for:
  - Partners of the125 GeV Higgs boson
  - SUSY
  - Other BSM objects (Dark Matter, etc.)

Standard Model Higgs Couplings HL-LHC

$h \to \gamma\gamma$	all production modes
$h \to ZZ^* \to 4l$	all production modes
$h \to WW^* \to l\nu l\nu$	0-, 1-, 2-jet final states
$h \to Z\gamma$	inclusive
$h \to bb$	in Wh and Zh production
$h \to \tau\tau$	VBF production
$h \to \mu\mu$	inclusive and in tth production

- Using zero-width approximation, i.e. model-independent, as not using Higgs width, not measurable at LHC
- Some parametrisations measure ratios $\lambda_{ij}=\kappa_i/\kappa_j$
- Minimal coupling fit assumes common coupling for all bosons, κ_V, and for all fermions, κ_f.
- Uncertainties given with & w/o theory uncertainties
- Searches for "invisible Higgs" decays

300 fb^{-1} vs. 3000 fb^{-1} Uncertainties

EXP. PRECISION
THEO. UNCERTAINTY

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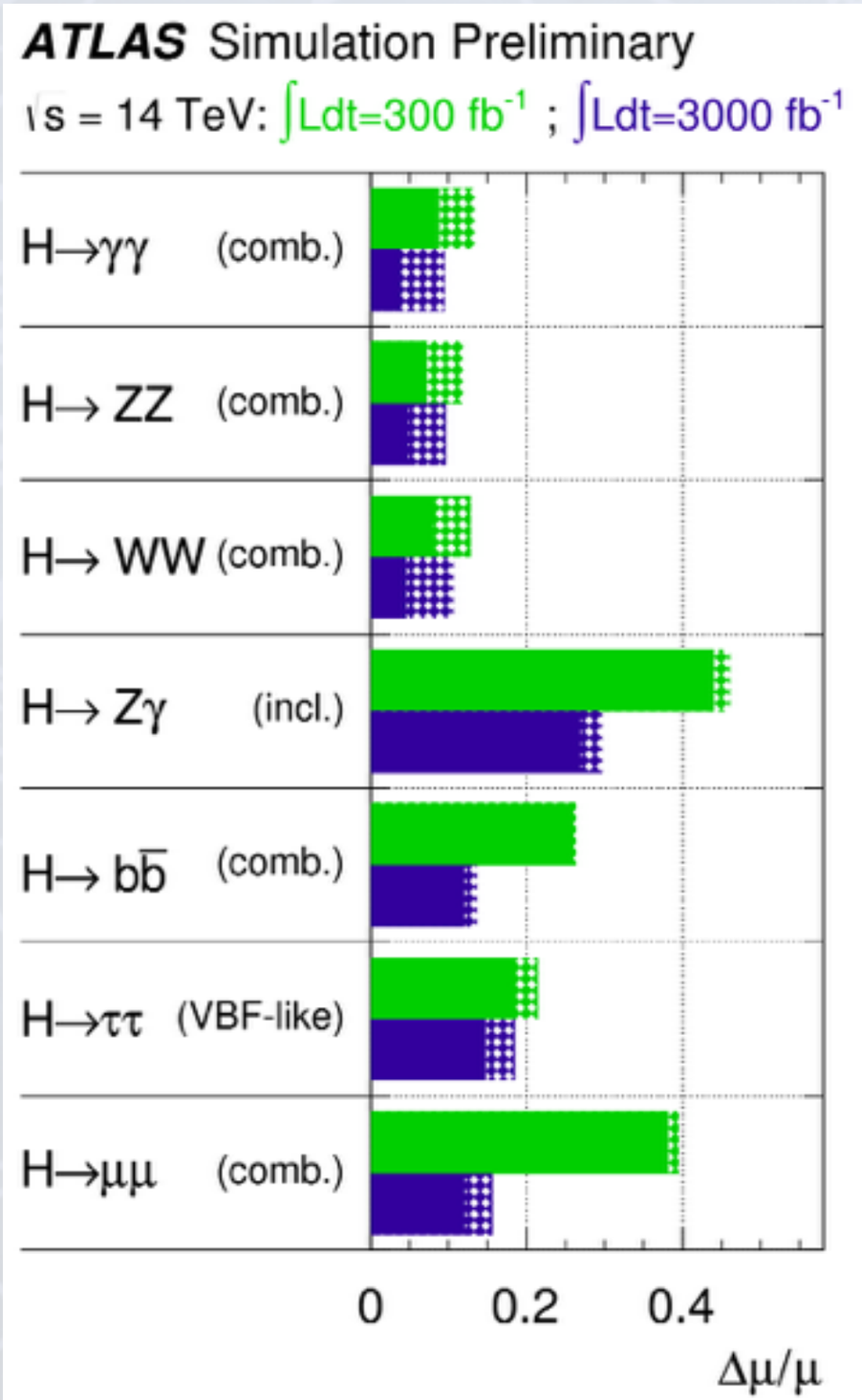

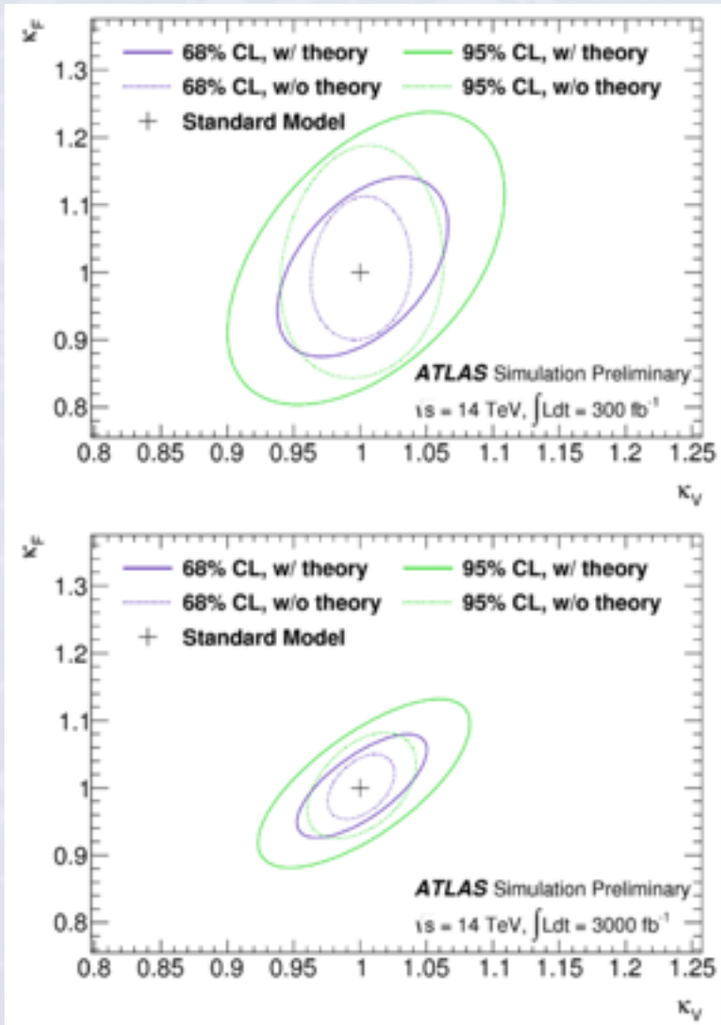

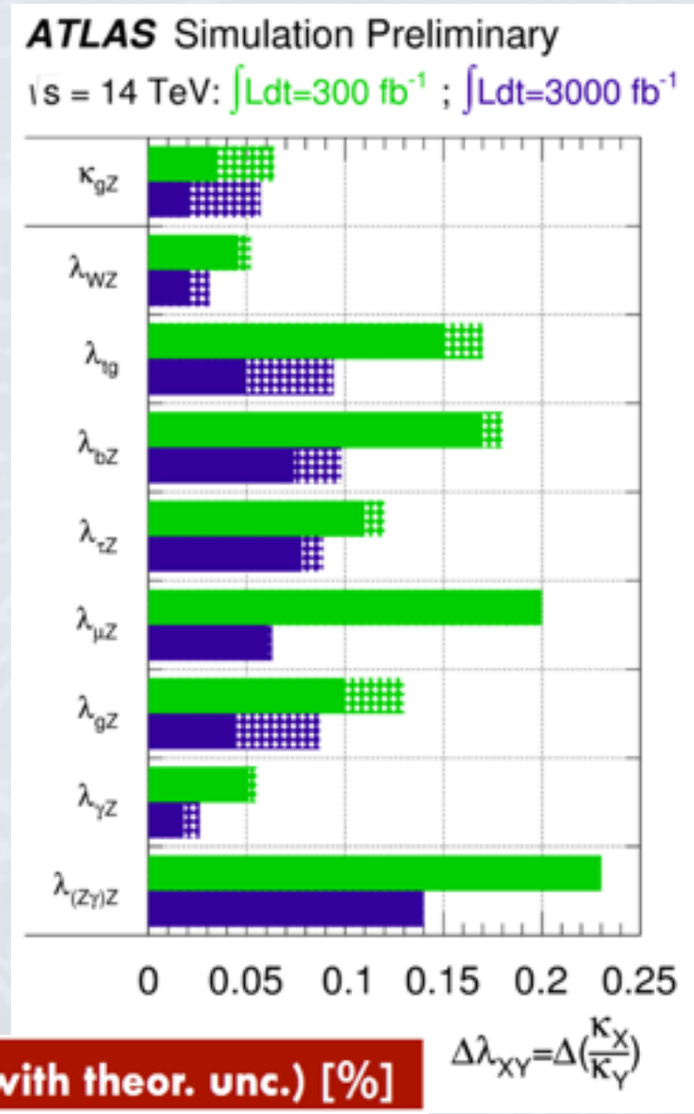

Coupling	Experimental precision (with theor. unc.) [%]	
	300 fb^{-1}	3000 fb^{-1}
κ_V	2.5 (4.3)	1.7 (3.3)
κ_f	7.1 (8.8)	3.2 (5.1)

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Yukawa Coupling Testing 300 vs 3000 fb^{-1}

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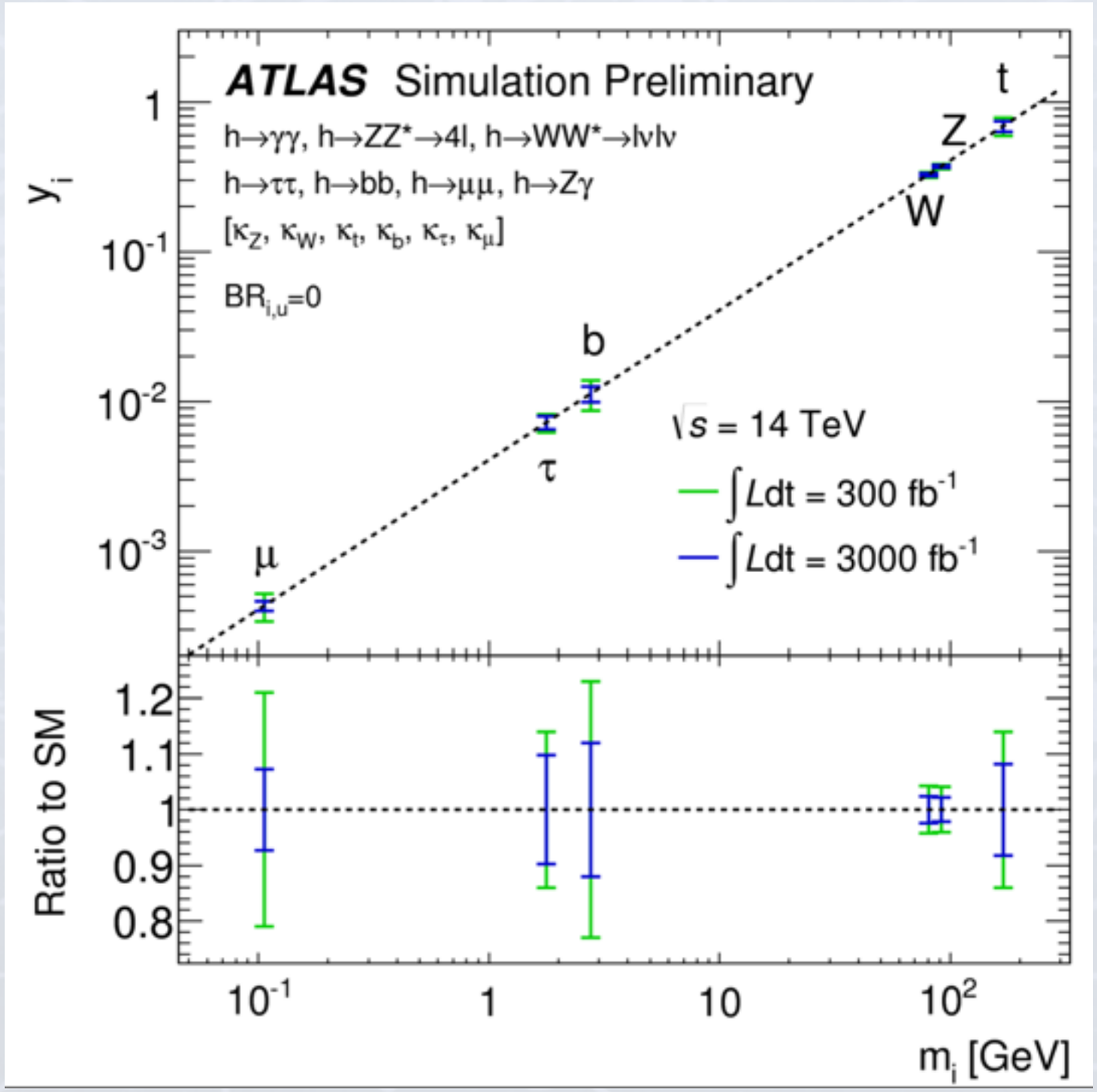

Fermions:
$y_i = k_i\, m_i\, v^{-1}$
Bosons:
$y_i = \sqrt{k_i}\, m_i\, v^{-1}$

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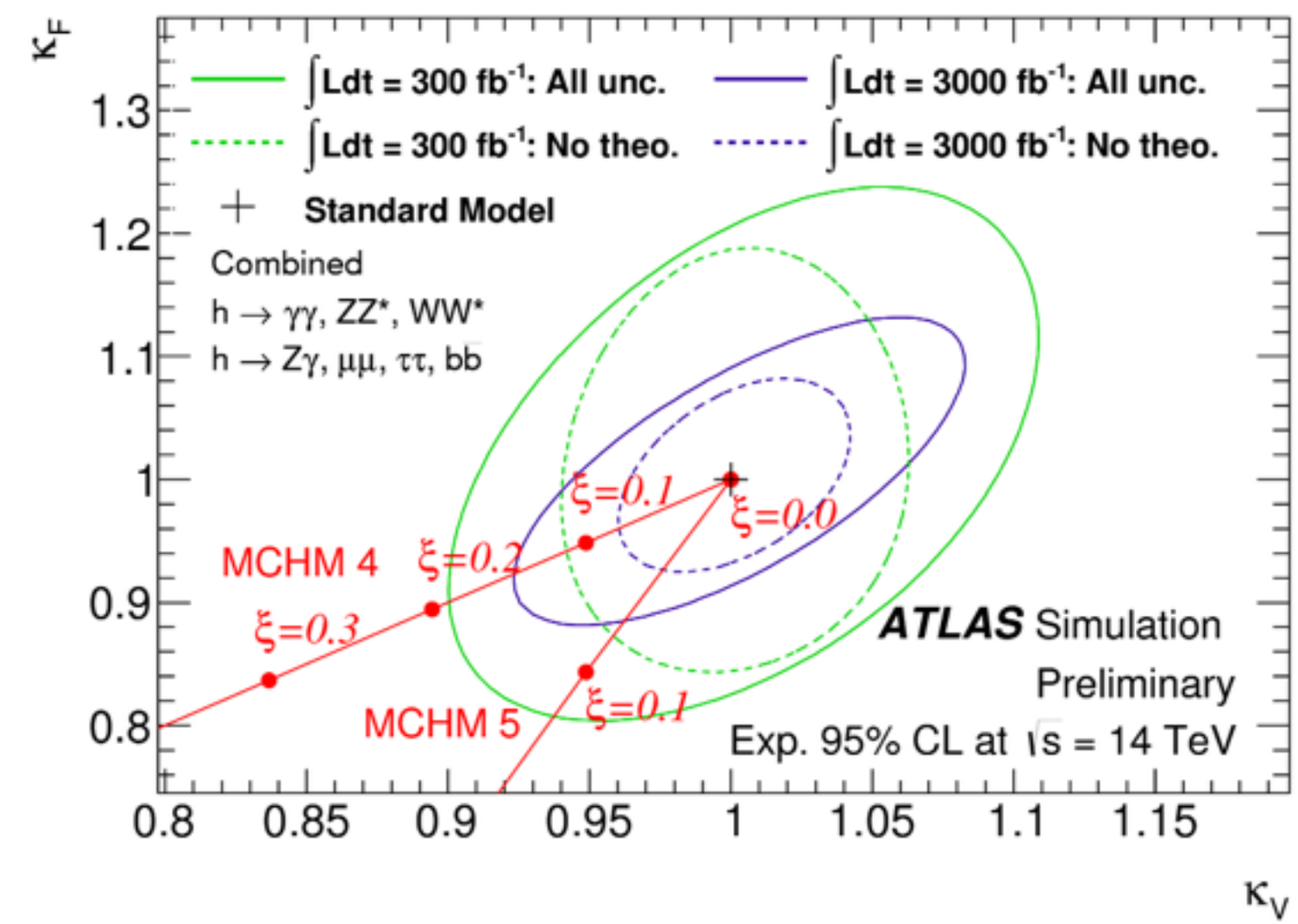
BSM Physics in Higgs Couplings HL-LHC

Minimal Composite Higgs is pseudo-Nambu-Goldstone boson

With non-SM fermion & boson couplings

$\xi = v^2/F^2$, with compositeness scale F VEV v



$$\kappa_V = \kappa_f = \sqrt{1-\xi}$$

In MCHM4

$$\kappa_V = \sqrt{1-\xi} \qquad \kappa_f = \frac{1-2\xi}{\sqrt{1-\xi}}$$

In MCHM5

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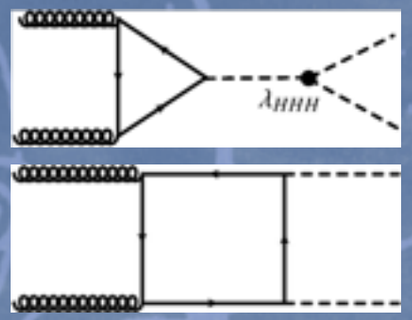
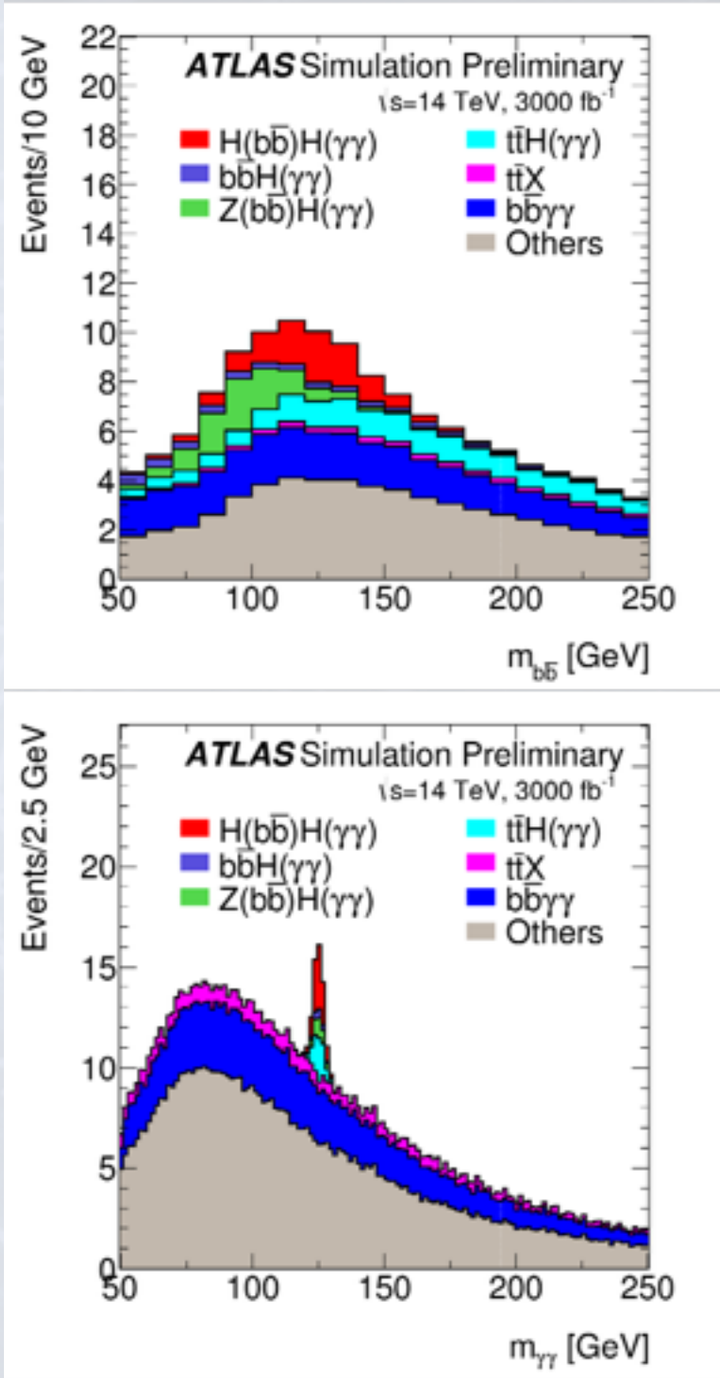
Higgs Pair Production HL-LHC



$gg \rightarrow hh \rightarrow bb\gamma\gamma$ limits on λ_{hhh}
$gg \rightarrow hh \rightarrow bb\tau\tau$ limits on λ_{hhh}
$gg \rightarrow hh \rightarrow bbbb$ resonant search for G^*_{KK}

- Dominant production at LHC gluon fusion - $\sigma(hh)^{NNLO+NNLL}$= 45.34 fb
- Other production modes ~30 times smaller cross-sections (not yet investigated)
- **10% theory uncertainties** (6% scale, 2% PDF, 2% α_S,)
  - All analyses used old calculation with $\sigma(hh)$= 40.8 fb



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$H \to \tau\tau$ $H \to bb$ channel Higgs Pair Production

HL-LHC

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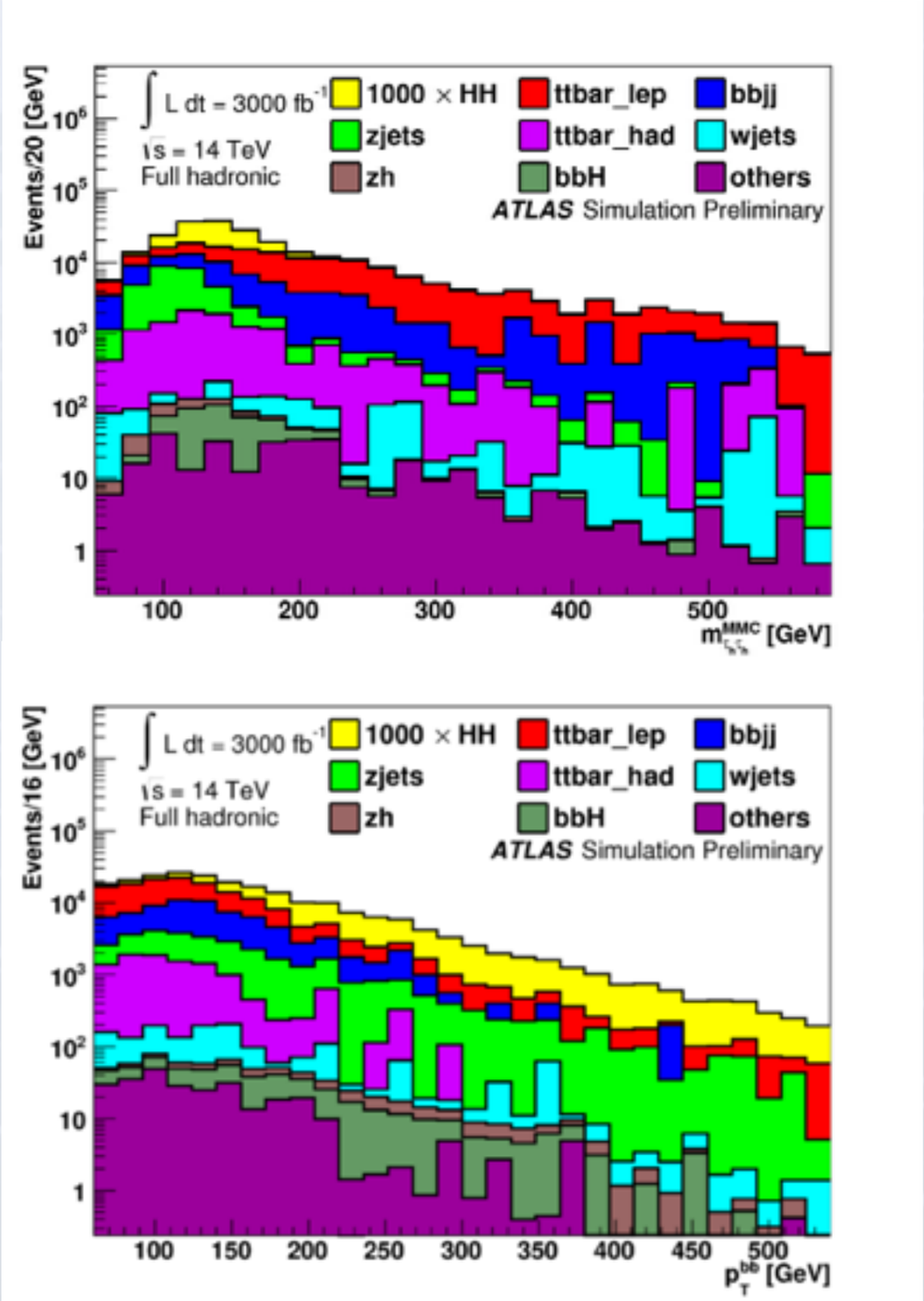
- 3 sub-channels:
  - $\tau_{lep}\tau_{lep}$,
  - $\tau_{lep}\tau_{had}$,
  - $\tau_{had}\tau_{had}$

  different triggers & event selections
- Track confirmation used to suppress pile-up
- Distributions of m_{bb} and p_T^{bb} in the $\tau_{had}\tau_{had}$ channel:



Cross-section limit:

$4.3 \times \sigma(HH \to bb\bar{\tau}^+\tau^-)$ at 95% CL

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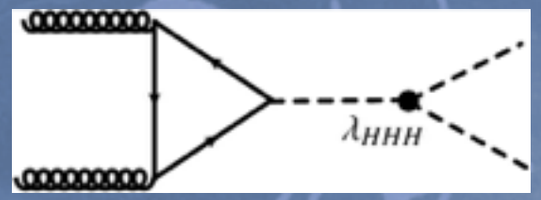
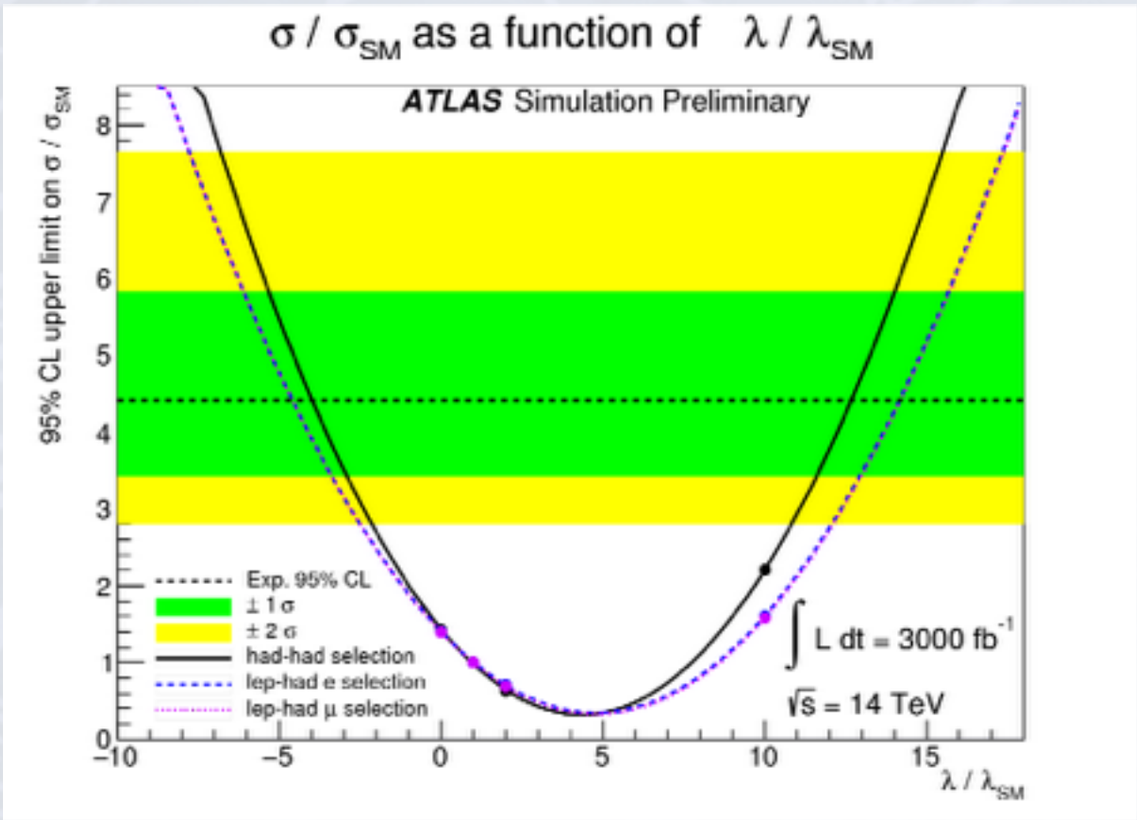
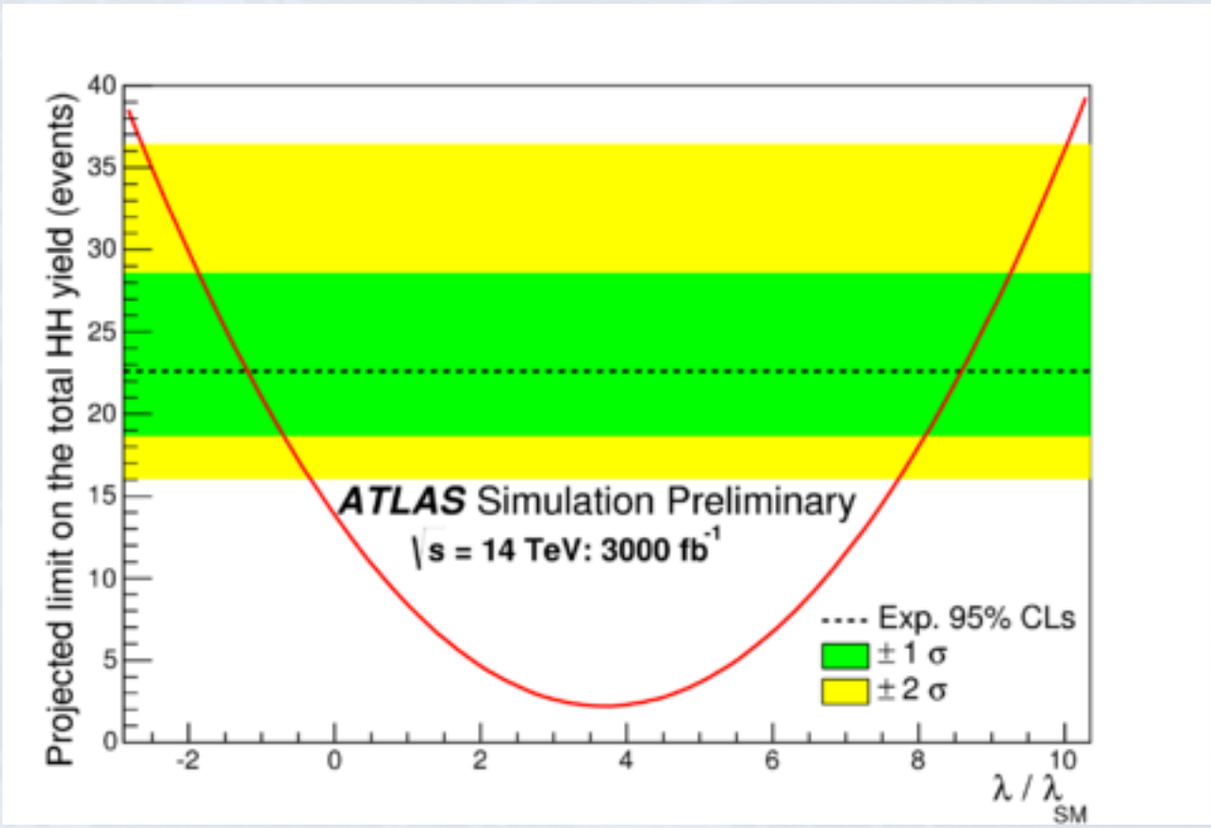
Limits on λ_{hhh} HL-LHC





bb ττ



bb γγ

Improvements possible by better
b-tagging efficiency & light jet rejection rate

Channel	Significance	Combined in channel	Total combined
e + jets	0.31	0.43	0.60
μ+jets	0.30		
$\tau_{\rm had}\tau_{\rm had}$	0.41	0.41	

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Graviton Resonance Search HH → BBBB

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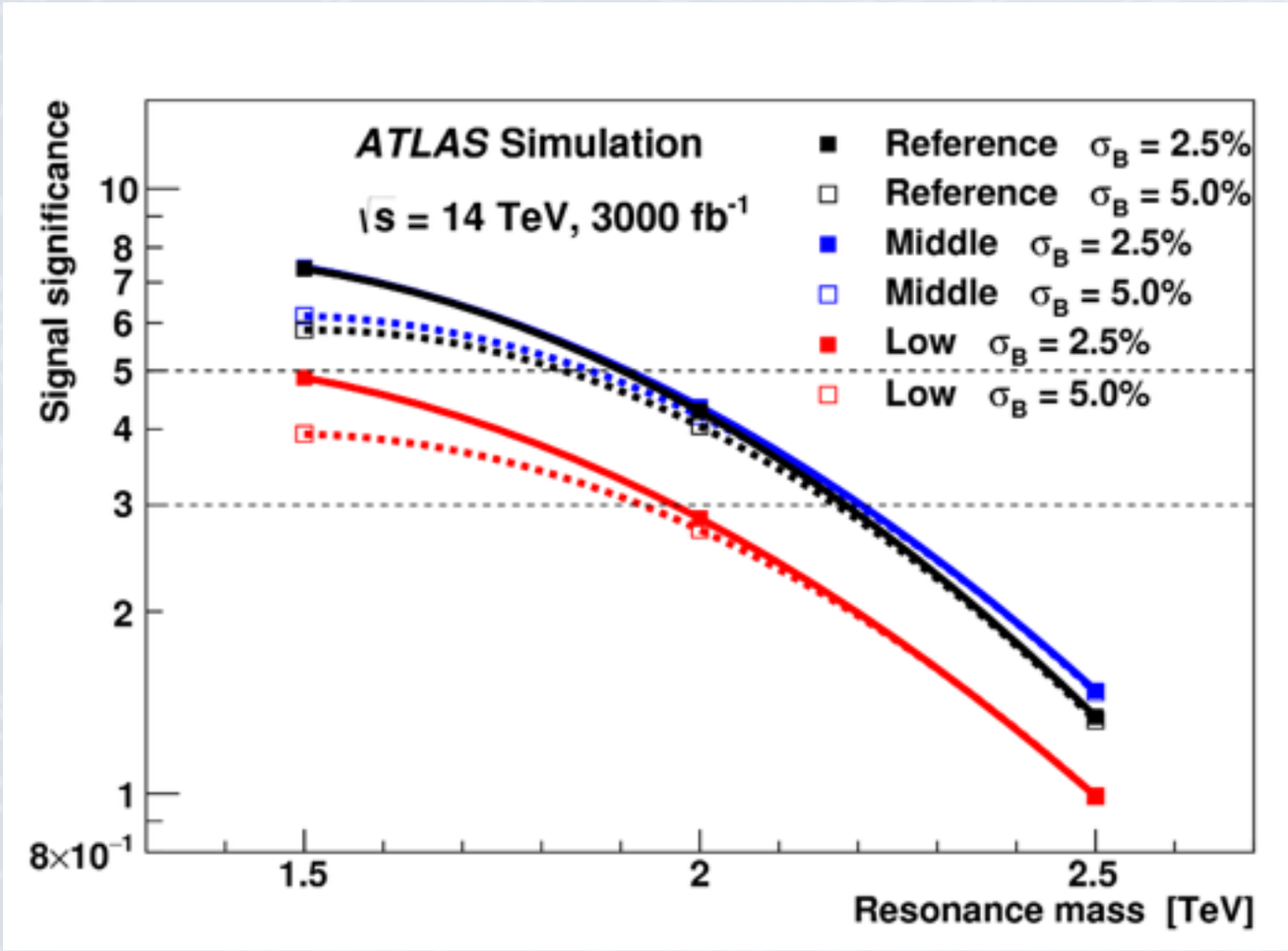


- μ=200
- 3000 fb-1
- 3 update scenarios
- 2 systematic uncertainties: 2.5% & 5%
- High 180 GeV jet threshold - pileup negligible
- 3 jet collections: large R, track & trigger jets

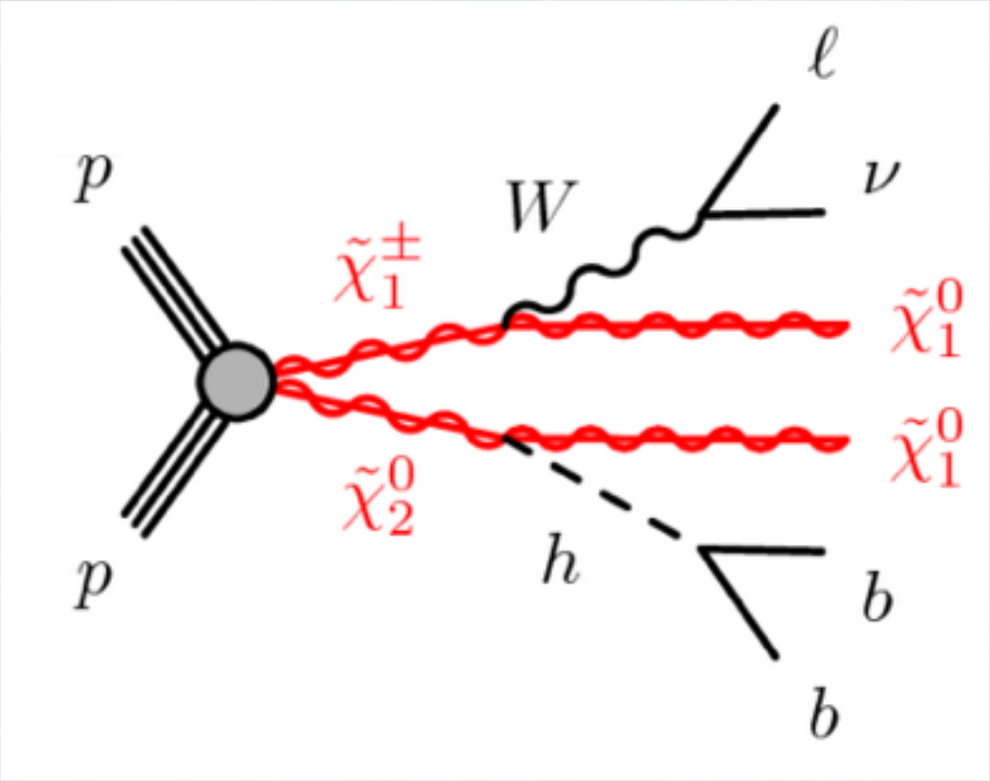
B-tagging performance increases significance -
Significance for G^*_{KK} with 2 TeV: 4.4

CERN-LHCC-2015-020

Supersymmetry Wh-mediated

SIMPLIFIED MODEL

$\chi^{\pm}_1\chi^0_2 \rightarrow l\ bb + E_T^{miss}$



- Pair-produced charginos & neutralinos
- Heavy sleptons & neutrinos
- Conservation of R-parity
- lightest neutralino is stable LSP
- mass eigenstates of SUSY partners from superposition of Higgs & EW gauge bosons

- Charginos and neutralinos have masses ~ 100 GeV
- With 100% branching ratio:
  - $\chi^{\pm}_1 \rightarrow W^{\pm}\chi^0_1$
  - $\chi^0_2 \rightarrow h\chi^0_1$

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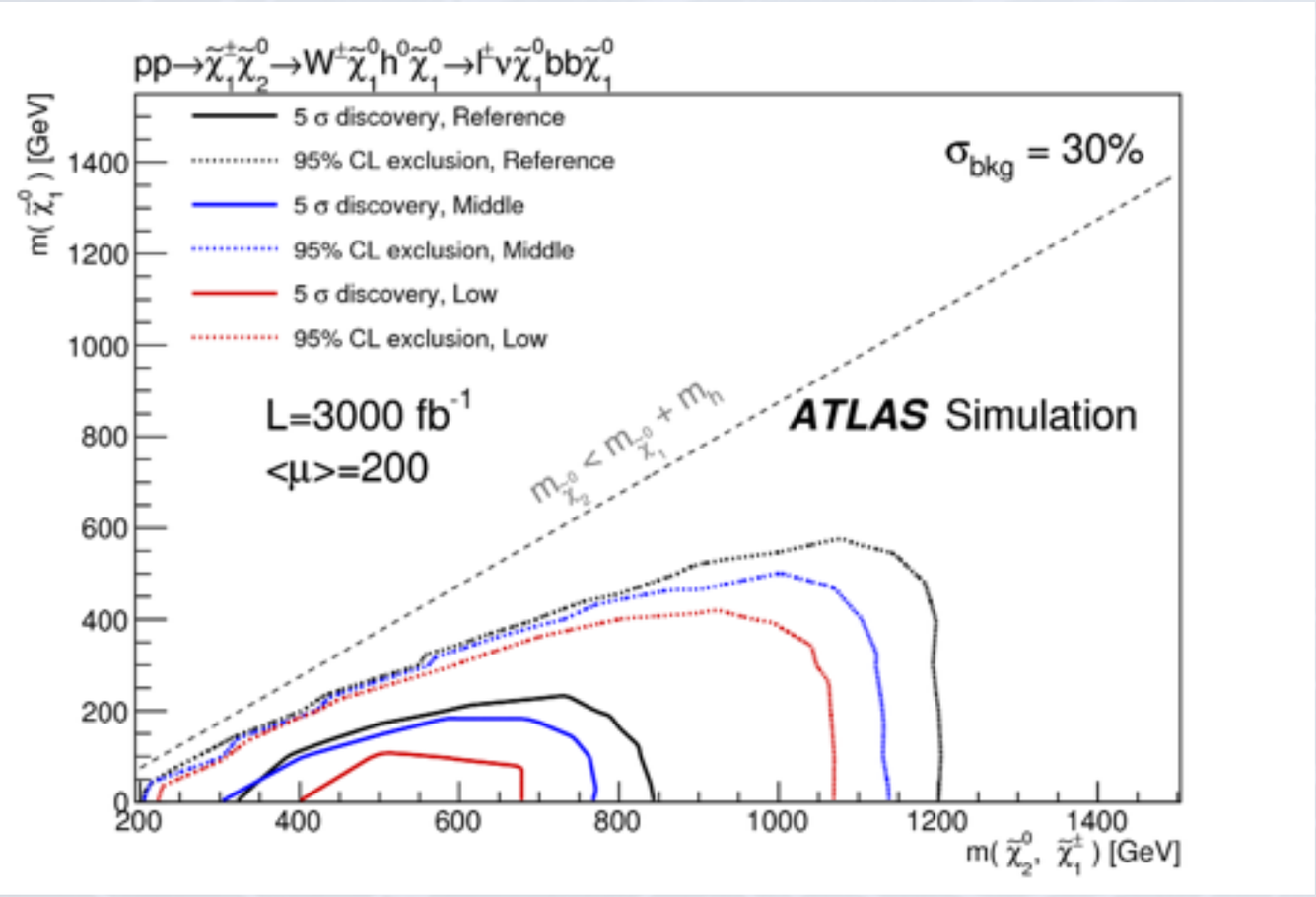
Electro-Weakinos Discovery Prospects HL-LHC



- μ=200
- Min. $p_T^{e,\mu}$ = 22,20 GeV object selection
- Calo & ITK upgrades improve b-tagging efficiency
- Total background systematic uncertainty 30%
- Trigger improvements not included

Discovery potential: $\chi^{\pm}_1 \chi^0_2$ mass 800 GeV

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& ATL-PHYS-PUB-2015-032

Conclusions

- Precise Higgs sector measurements necessary to understand EWSB - including vector boson scattering
- Higgs Couplings to elementary Fermions & Bosons
  - 2-3 smaller uncertainties 300 fb^{-1} → 3000 fb^{-1}
  - highest improvement potential: VH & ttH production
  - meas. precision limited by theo. uncert. $\sigma(gg \to h)$
- Di-Higgs production
  - First Observation at HL-LHC possible
  - given tiny rates we should study as many channels as possible, but O(1) limit set by λ_{hhh} (with room for analysis optimisation)
- Direct searches for New Physics can be extended further
  - Limits on Higgs compositeness scale in 1 TeV range
  - Up to 2TeV sensitivity for Kaluza-Klein Graviton
  - Sensitivity to electro-weakinos in 800 GeV range
- Theory input crucial to decrease uncertainties

MANY STUDIES WITH DIFFERENT LAYOUTS, ETA=4 AND MU=200 ARE ONGOING