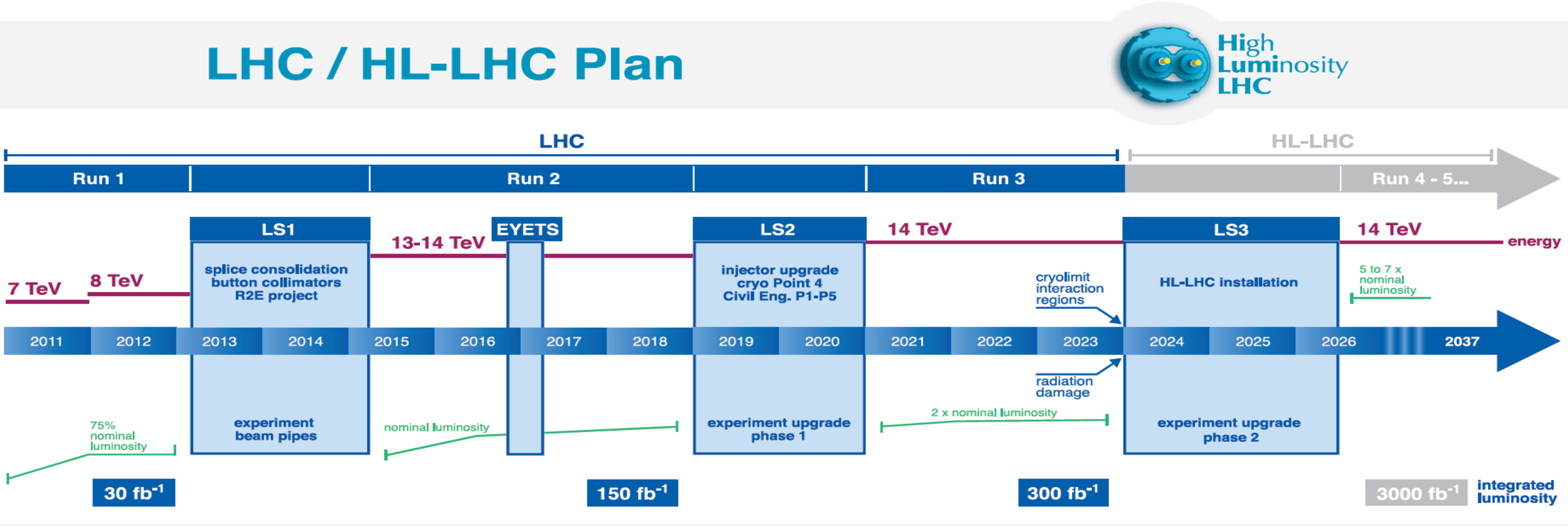
HIGH-LUMINOSITY LHC PROSPECTS WITH THE UPGRADED ATLAS DETECTOR

Magdalena Slawinska, Nikhef, Amsterdam
for the ATLAS Collaboration

DIS2016, 11-15 April 2016, Hamburg

HL-LHC



LHC / HL-LHC Plan
High Luminosity LHC
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
LS3
7 TeV
8 TeV
13-14 TeV
14 TeV
14 TeV
energy
splice consolidation
button collimators
R2E project
injector upgrade
cryo Point 4
Civil Eng. P1-P5
cryolimit
interaction
regions
HL-LHC installation
5 to 7 x
nominal
luminosity
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2037
radiation
damage
75%
nominal
luminosity
experiment
beam pipes
nominal luminosity
experiment upgrade
phase 1
2 x nominal luminosity
experiment upgrade
phase 2
30 fb-1
150 fb-1
300 fb-1
3000 fb-1
integrated
luminosity

Expected High Luminosity conditions

- centre of mass energy 14 TeV
- instantaneous luminosity up to 7.5 x 10^{34} cm^{-2} s^{-1}
- maximal bunch crossing rate of 40 MHz
- number of proton-proton interactions per bunch crossing $\mu = 200$

Scoping Document (https://cds.cern.ch/record/2055248, 2015) analyses physics capabilities for upgraded ATLAS layout (see next slide).

Analyses described here do not include full upgrades in the Tracker, such as an Inner Tracker coverage extended to 4.0 units of rapidity.

Most of analyses analyses used an older estimation $\mu = 140$

Forseen upgrades of ATLAS

- **Trigger and Data Acquisition**
- Two-Level hardware trigger with L0 up to 1MHz and L1up to 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
- **Inner Tracker**
- Completely new, all-silicon tracker
- Extending Pixel Detector to $|\eta| < 4$
- **Calorimeters**
- LAr forward electromagnetic 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**
- Addition of RPCs in the barrel, $|\eta| < 1$

NSW in the end-cap at Phase 1

Physics motivation for HL-LHC

- Understanding EWSB
  - ultimate test if Higgs is responsible for SM EWSB is the measurement of its potential (self-coupling λ_{hhh})
  - testing vector-boson scattering probes composite nature of the Higgs
  - precise measurements of Yukawa couplings
- Direct searches for BSM Physics coupling to Higgs
  - deviations in couplings to SM particles
  - Heavy Scalars
  - SUSY

SM Higgs couplings

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

Higgs couplings framework

- In zero-width approximation

$$\sigma \cdot B\,(i \to H \to f) = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_H}$$

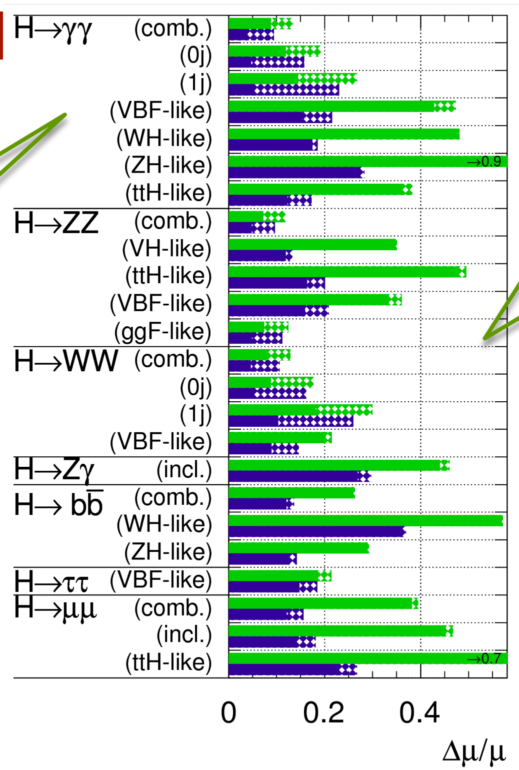
- κ parameters correspond to LO degrees of freedom:

$\sigma_i(ii \rightarrow h)$ and $\Gamma_i\,(h \rightarrow ii)$ scale with κ_i^2 compared to the SM prediction

$$\frac{\sigma \cdot B\,(gg \to H \to \gamma\gamma)}{\sigma_{\rm SM}(gg \to H) \cdot B_{\rm SM}(H \to \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

- To not use total width Γ_h some parametrizations 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 will be given with and w/o theory uncertainties

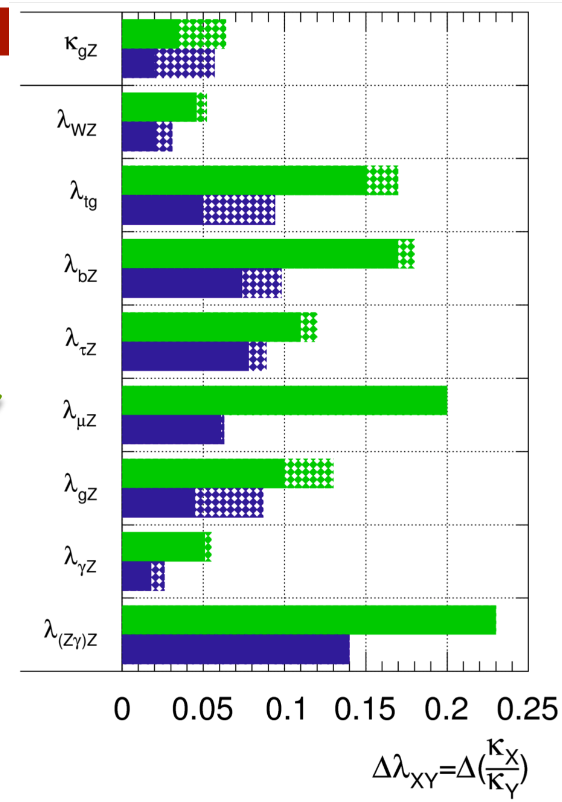
Uncertainties; 300 fb^{-1} vs 3000 fb^{-1}



largest theor. unc. in gg→ h, PDFs, jet-bin

Relative uncertainty on the signal strength

Relative uncertainties on coupling ratios



minimal coupling fit

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)

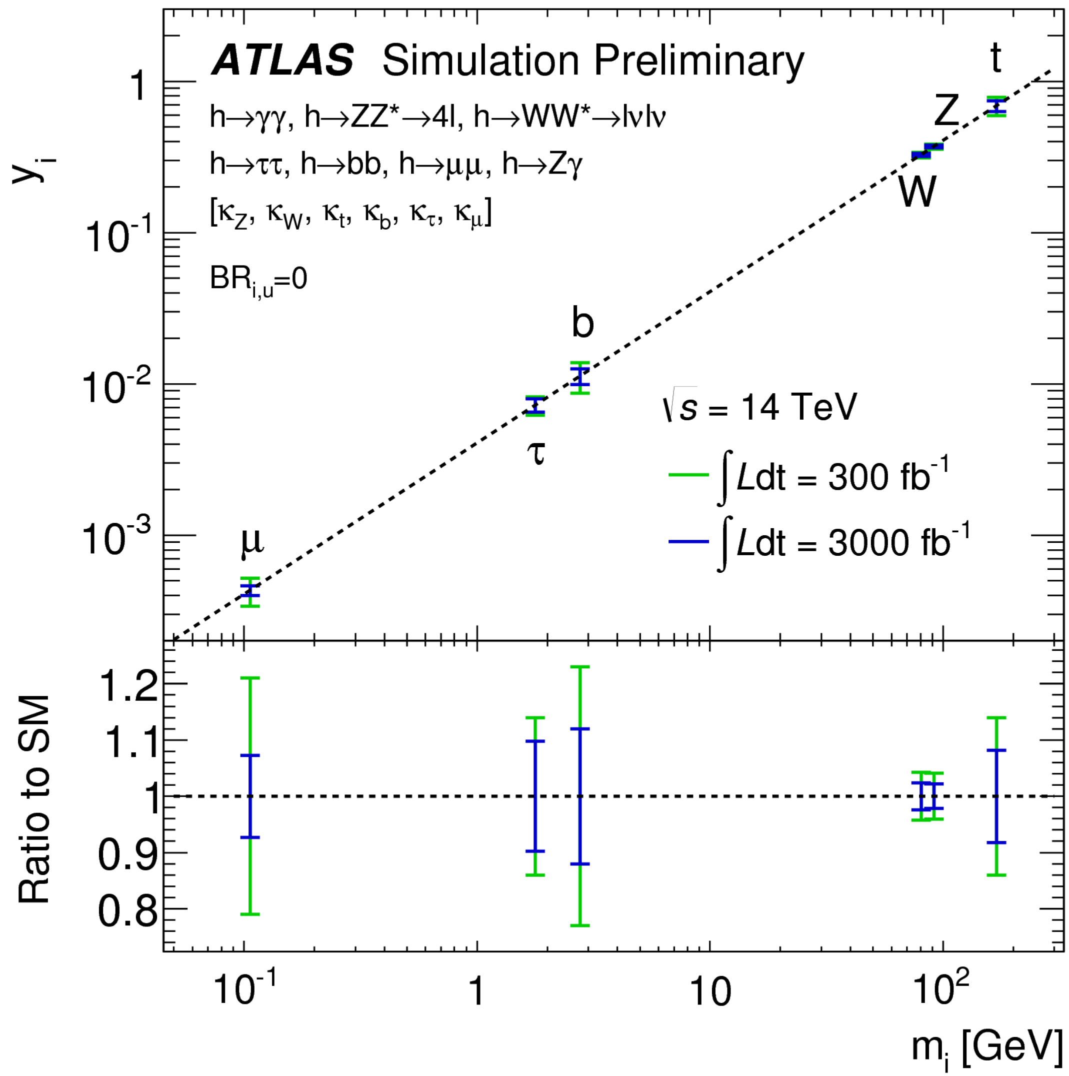
Testing Yukawa interactions

$$y_i = \sqrt{\kappa_i}\frac{m_i}{v}$$

for bosons

$$y_i = \kappa_i\frac{m_i}{v}$$

for fermions



BSM Physics in Higgs Couplings

$h \to \gamma\gamma$	inclusive & 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
$h \to Z(\to ll)\gamma$	inclusive and in VBF production
$h \to \tau\tau$	VBF production
$h \to \mu\mu$	inclusive and in tth production
$h \to b\bar{b}$	in Wh and Zh production

Minimal Composite Higgs Model

- Higgs is a composite pseudo-Nambu-Goldstone boson.
- Non-SM couplings to bosons and fermions:

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

In MCHM4

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

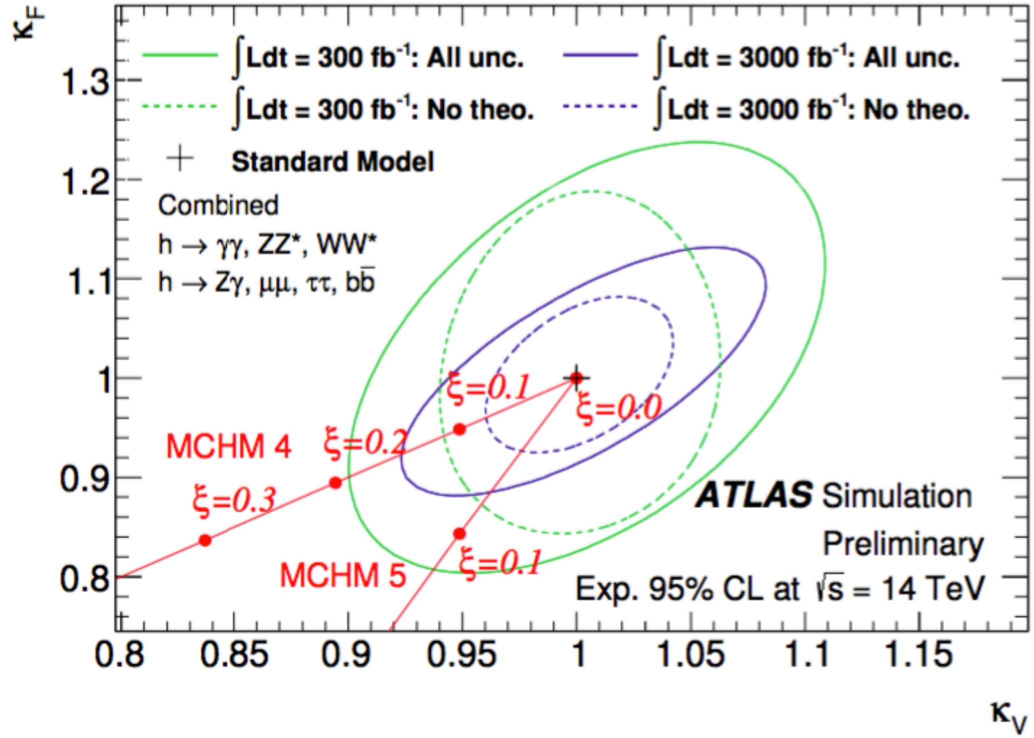
In MCHM5

- $\xi = v^2/F^2$, compositeness scale **F**, and VEV **v**

$\xi \rightarrow 0$ is the SM

no contributions from new heavy resonances

Limits on Higgs compositeness scale



Expected 95% CL lower limit on Higgs compositeness scale F

Model	$300\ fb^{-1}$		$3000\ fb^{-1}$	
	All unc.	No theory unc.	All unc.	No theory unc.
MCHM4	620 GeV	810 GeV	710 GeV	980 GeV
MCHM5	780 GeV	950 GeV	1.0 TeV	1.2 TeV

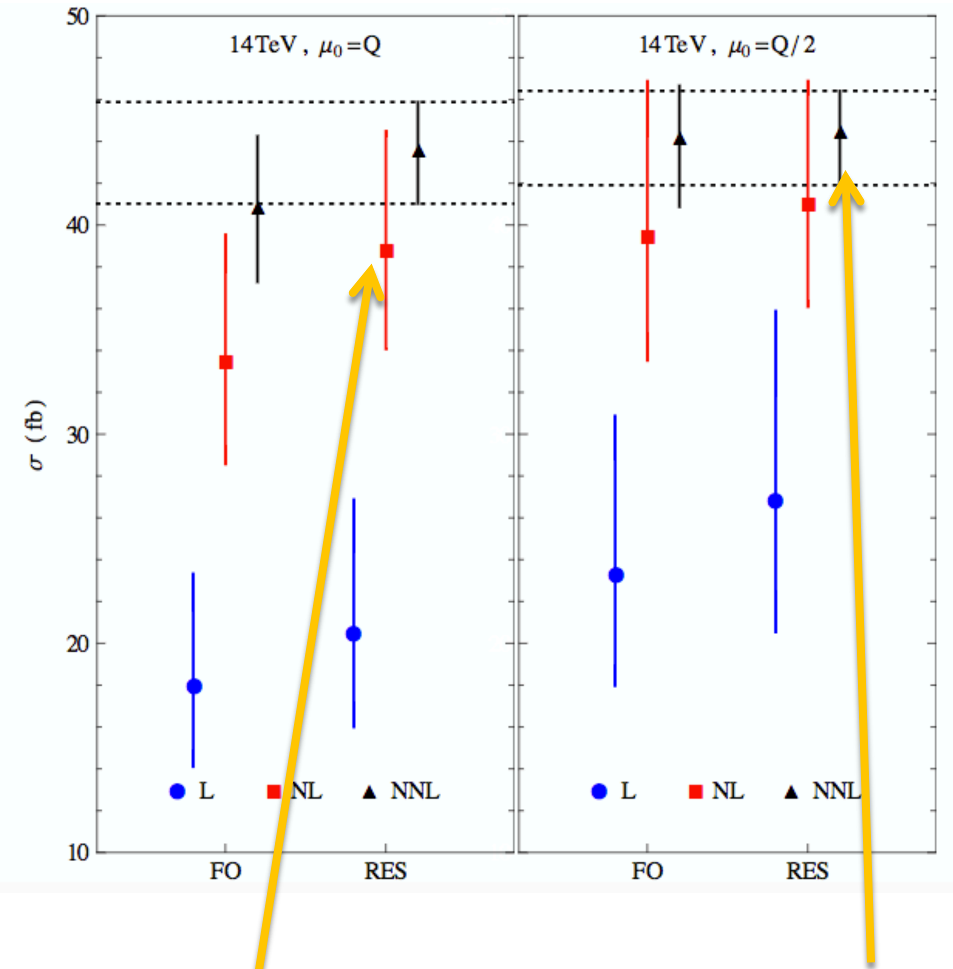
Higgs Pair Production

$$gg \to hh \to b\bar{b}\gamma\gamma$$ limits on λ_{hhh}

$$gg \to hh \to b\bar{b}\tau\tau$$ limits on λ_{hhh}

$$gg \to hh \to b\bar{b}b\bar{b}$$ resonant search for G^*_{KK}

Higgs pair production in the SM



old calculation

new calculation

- The dominant production at the LHC is gluon fusion

σ (hh)$^{NNLO+NNLL}$= 45.34 fb

- cross-sections of other production modes ~30 times smaller (not yet investigated)

- 6% scale, 2% PDF, 2% $\alpha_{S,}$

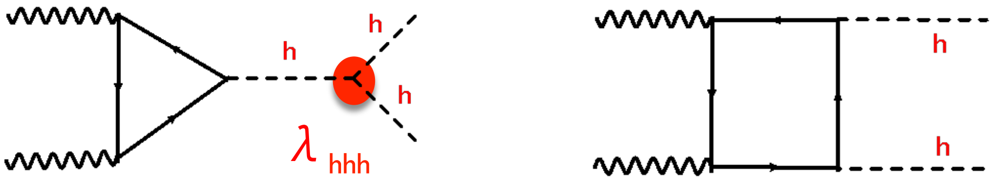
10% theory uncertainties

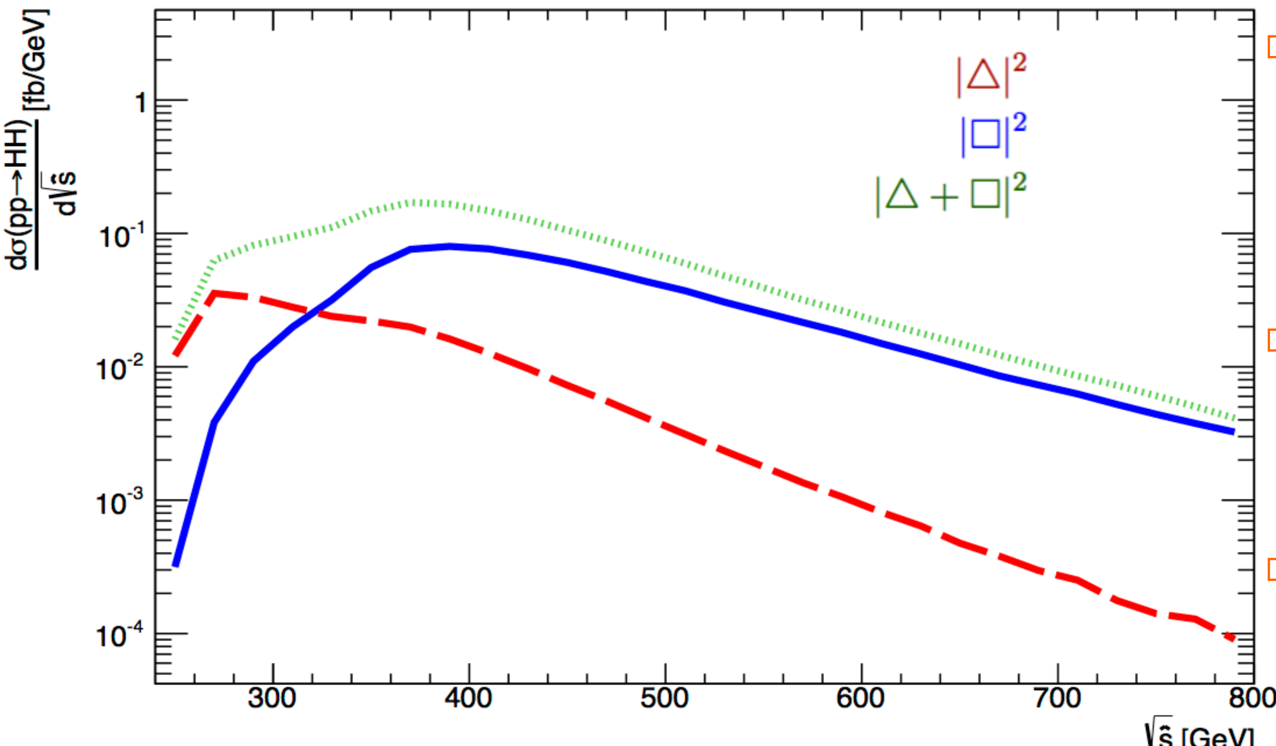
- All analyses used old calculation

with σ (hh)= 40.8 fb

- LO differential distributions used

Observation of 2 Higgses or measurement of λ_{hhh}?

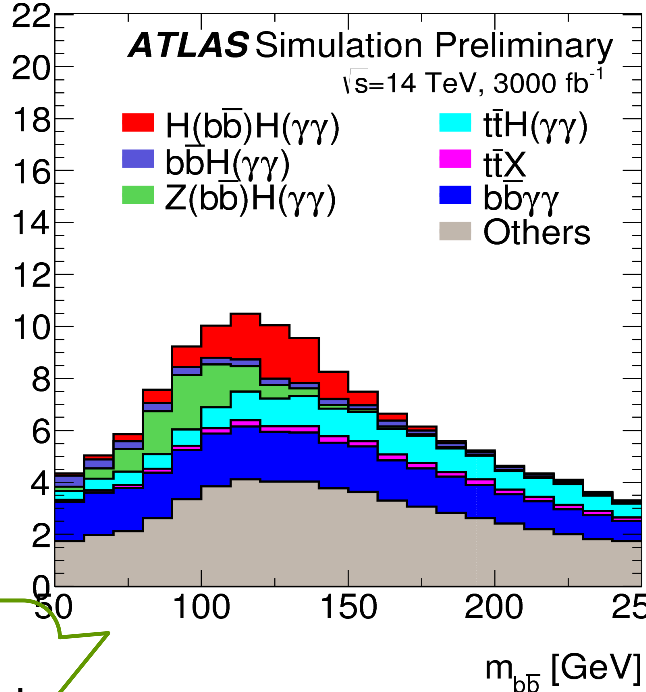


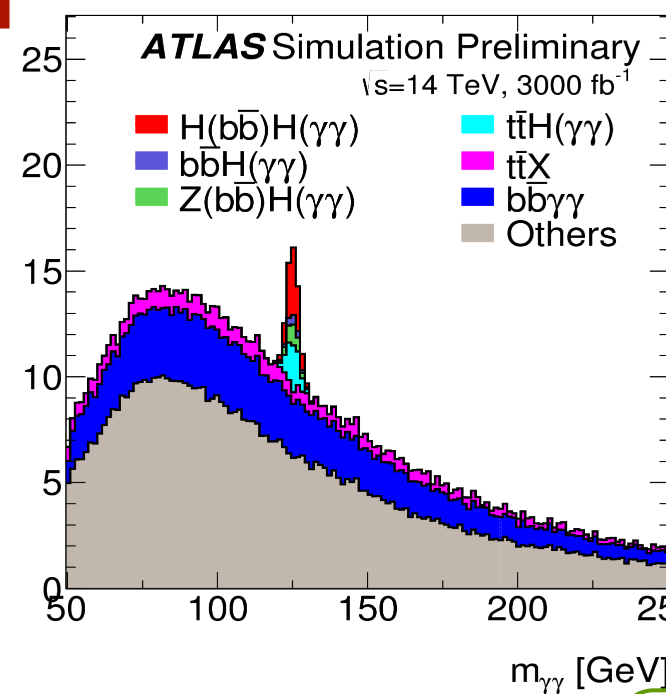


arXiv:1408.5010 using LO Madgraph

- large destructive interference decreases cross-section
- total rates largest at $\sqrt{s} > 2m_h$
- $\triangle$ only contributes at $\sqrt{s} \cong 2m_h$

$hh \to b\bar{b}\gamma\gamma$





dominant backgrounds from light jets

different photon fake rates

Expected Yields	Barrel	End-cap	Total
signal	6.7±0.1	1.8±0.1	8.4±0.1
total background	29.1±2.7	18.0±2.3	47.1±3.5
$S/\sqrt{B}$	1.2	0.4	1.3

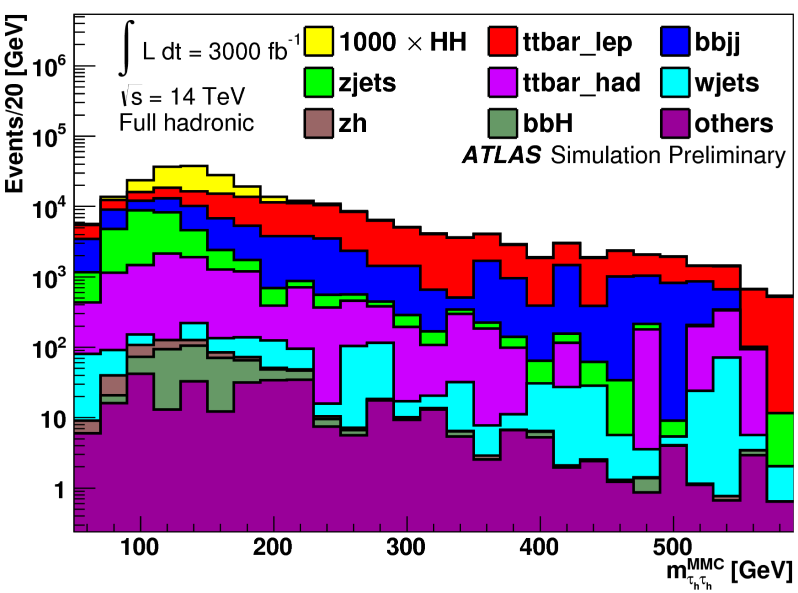
significance

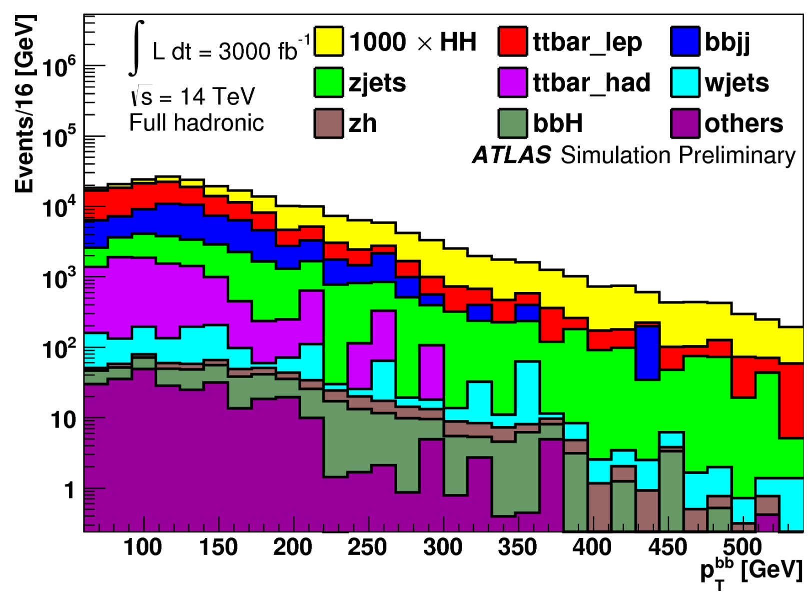
$hh \to b\bar{b}\tau\tau$

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

with different triggers and slightly different event selections

- track confirmation used to suppress pile-up
- Distributions of m_{bb} and p_T^{bb} in the $\tau_{had}\tau_{had}$ channel:



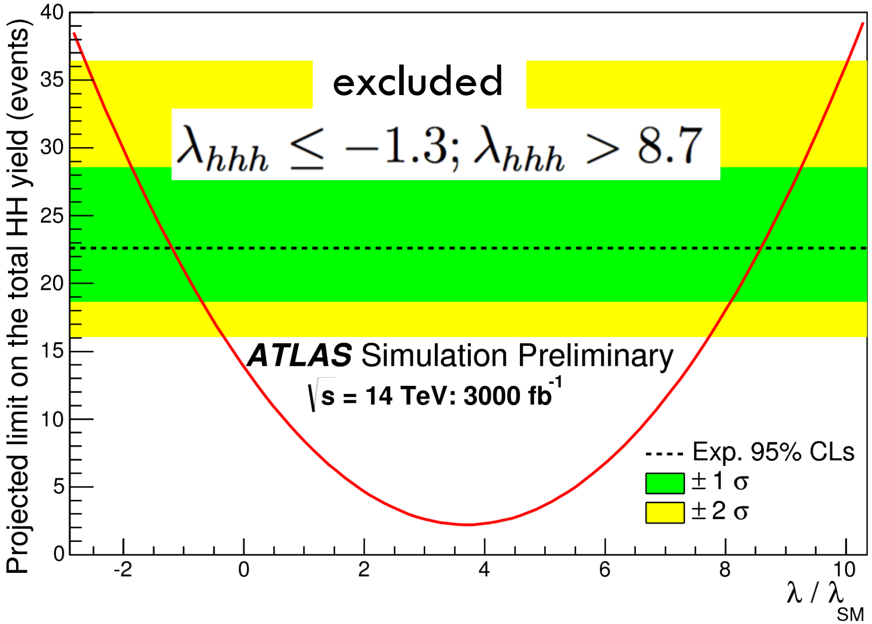


- Limit on cross-section $4.3\times\sigma(HH\to b\bar{b}\,\tau^+\tau^-)$ at 95% CL

Limits on λ_{hhh}

assuming no other deviations from SM

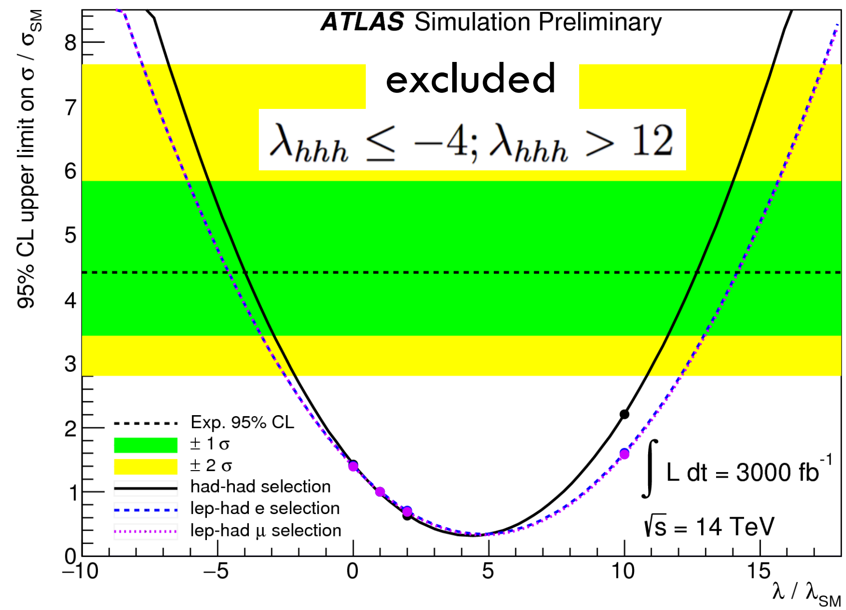
bb $\gamma\gamma$



- room for further improvements:
- b-tagging efficiency
- higher light jet rejection rates

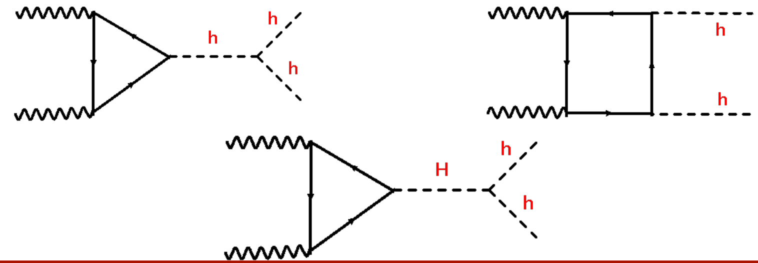
bb $\tau\tau$

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



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	

Resonant Higgs Pair production



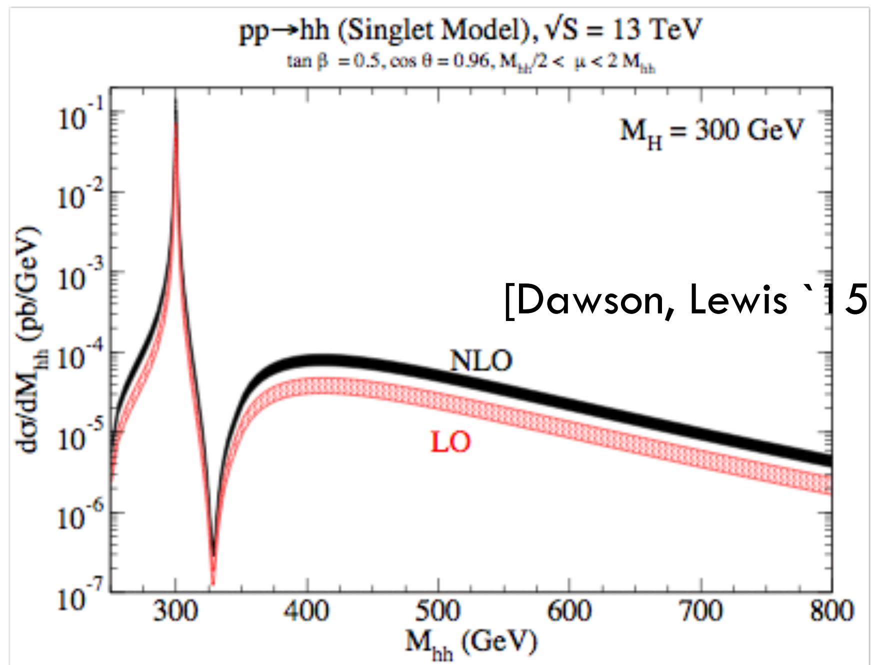
- If a Dark Matter scalar S couples to Higgs
- Modified Higgs – S potential

S has has Z_2 symmetry and VEV ≠0

$$V = -m^2\Phi^\dagger\Phi - \mu^2 S^2 + \lambda_1(\Phi^\dagger\Phi)^2 + \lambda_2 S^4 + \lambda_3\Phi^\dagger\Phi S^2$$

EWSB

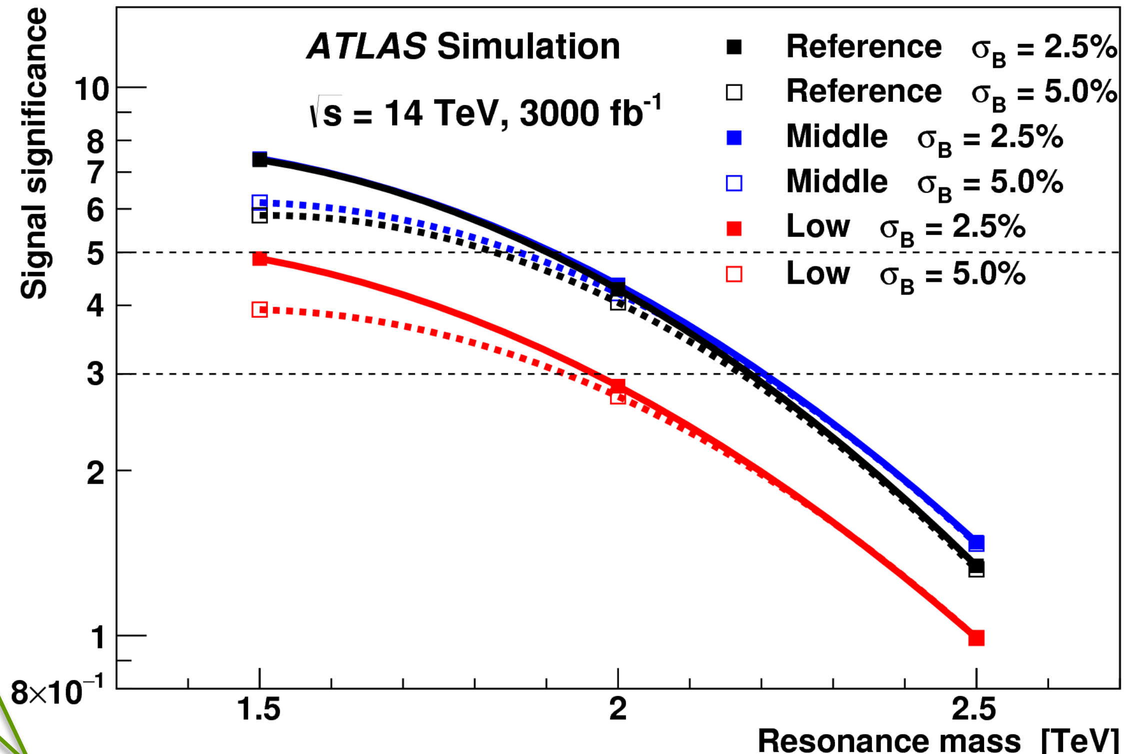
$$h = \cos\alpha\,\phi_0 + \sin\alpha\, s$$
$$H = -\sin\alpha\,\phi_0 + \cos\alpha\, s$$



[Dawson, Lewis `15]

Resonant search for Graviton with $hh \rightarrow b\bar{b}b\bar{b}$

3 collections of jets:
- large R
- track-jets
- trigger jets



pileup negligible due to high jet thresholds 180 GeV

sensitivity gain due to b-tagging performance

$\mu = 200$

Significance for G^*_{KK} with 2 TeV mass: 4.4

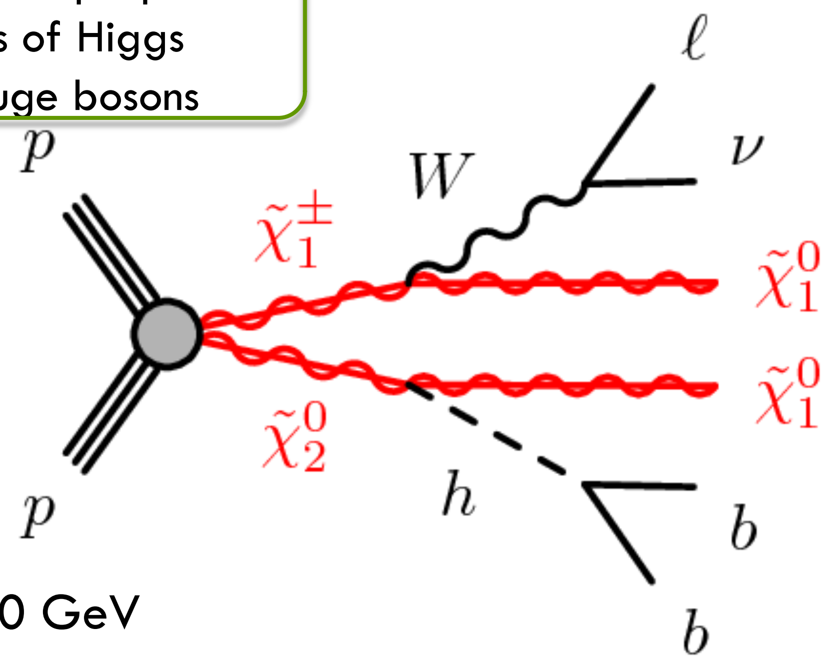
Supersymmetry

$\chi^{\pm}_{1}\chi^{0}_{2} \rightarrow l\,bb + E_T^{miss}$

Wh-mediated simplified model

mass eigenstates from superposition of the SUSY partners of Higgs and electroweak gauge bosons

- R-parity conservation
- charginos and neutralinos are pair-produced
- heavy sleptons and sneutrinos
- lightest neutralino is the stable LSP



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

100% branching ratios

HL-LHC prospects for discovering electro-weakinos

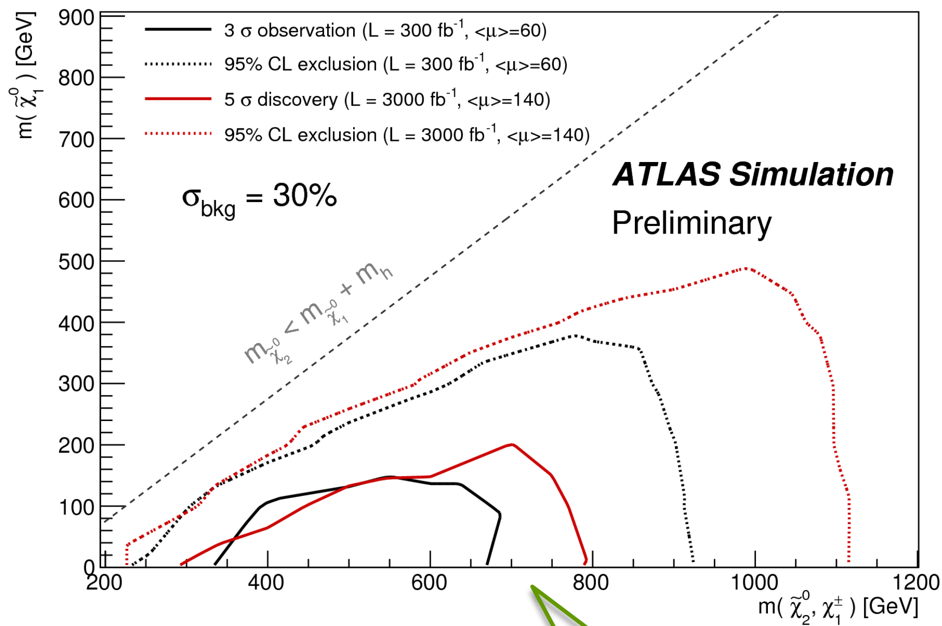
- Expected $\mu = 140$
- Object selection with minimum

$p_T^{e,\mu}$ = 22, 20 GeV

(improvements in the trigger not included)

- improvements in b-tagging efficiency from ITk and Calo
- 30% systematic uncertainty on total background (consistent with Run 1)
- HL-LHC discovery potential: $\chi^{\pm}_1 \chi^0_2$ mass: 800 GeV

$\mu = 200$



improvement wrt. Run3

Conclusions (I/II)

- Understanding electroweak symmetry breaking requires precise measurements in the Higgs sector that can be done at HL-LHC.
- Difficult conditions of HL-LHC require detector upgrades
- Higgs couplings to bosons and fermions
  - uncertainties 2-3 times smaller that with 300 fb^{-1}
  - largest improvements expected in VH and ttH production
  - precision of measurements limited by theor. uncert. of $\sigma(gg \rightarrow h)$
- Di-Higgs production
  - could be observed for the first time at HL-LHC
  - O(1) limits set on λ_{hhh} (room for analysis optimisation)

improvements since Run1 from N^3LO

Conclusions (II/II)

- With ATLAS at HL_LHC direct searches for New Physics can be extended further
  - Limits on Higgs compositeness scale in the range of 1 TeV
  - Sensitivity to Kaluza-Klein Graviton up to 2 TeV
  - Sensitivity to electro-weakinos in the 800 GeV mass range

- For all analyses theory input crucial to significantly decrease uncertainties

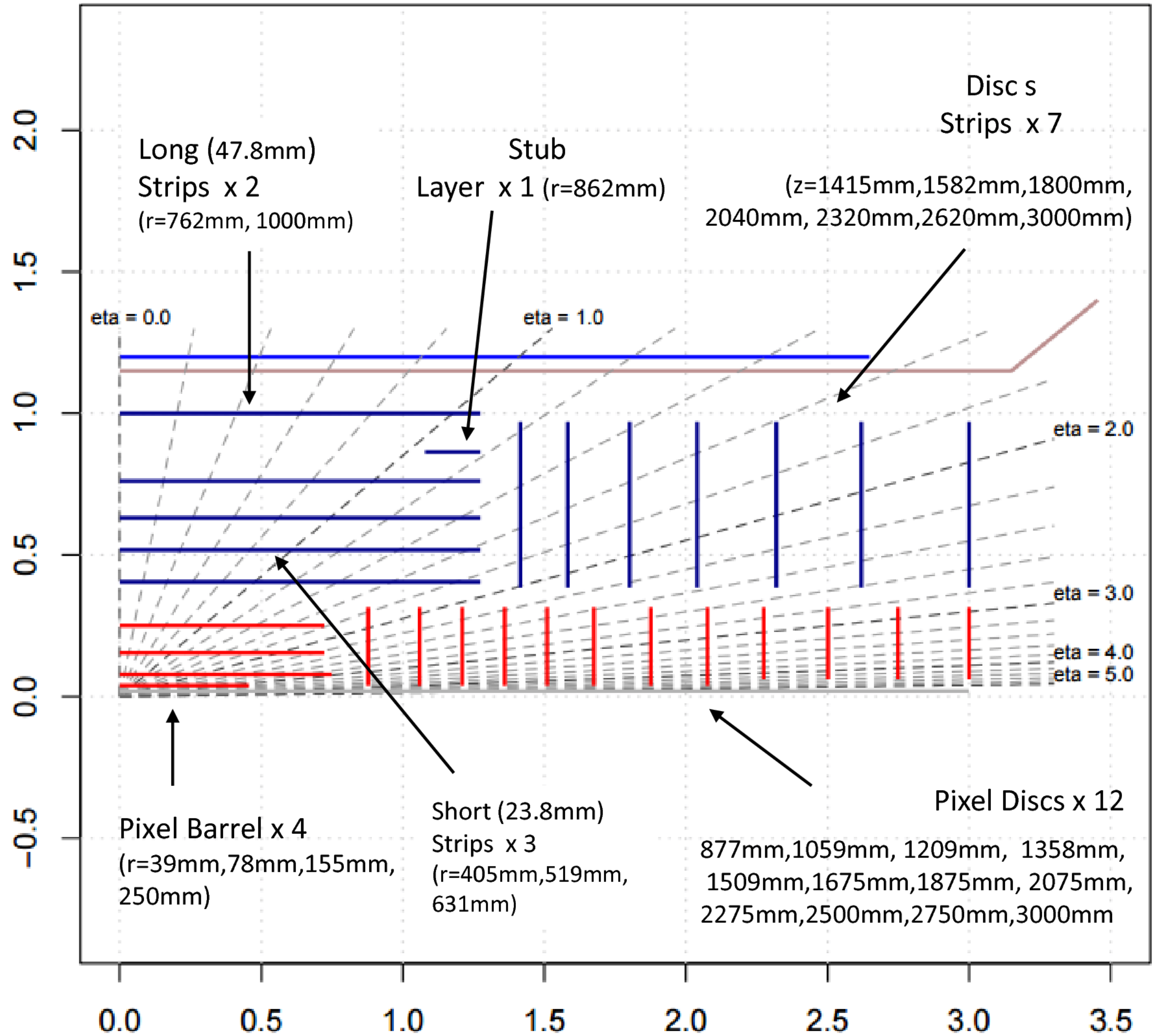
Run1 results from differential distributions not taken into account

Bibliography

- Upgrade design documents:
  - Scoping Document: https://cds.cern.ch/record/2055248
  - Phase II Upgrade Letter of Intent: https://cds.cern.ch/record/1502664
- Physics analyses:
- Higgs couplings: ATL-PHYS-PUB-2014-016, ATL-PHYS-PUB-2014-017
- Higgs pairs: ATL-PHYS-PUB-2014-019, ATL-PHYS-PUB-2015-046
- SUSY: ATL-PHYS-PUB-2013-011, ATL-PHYS-PUB-2014-010

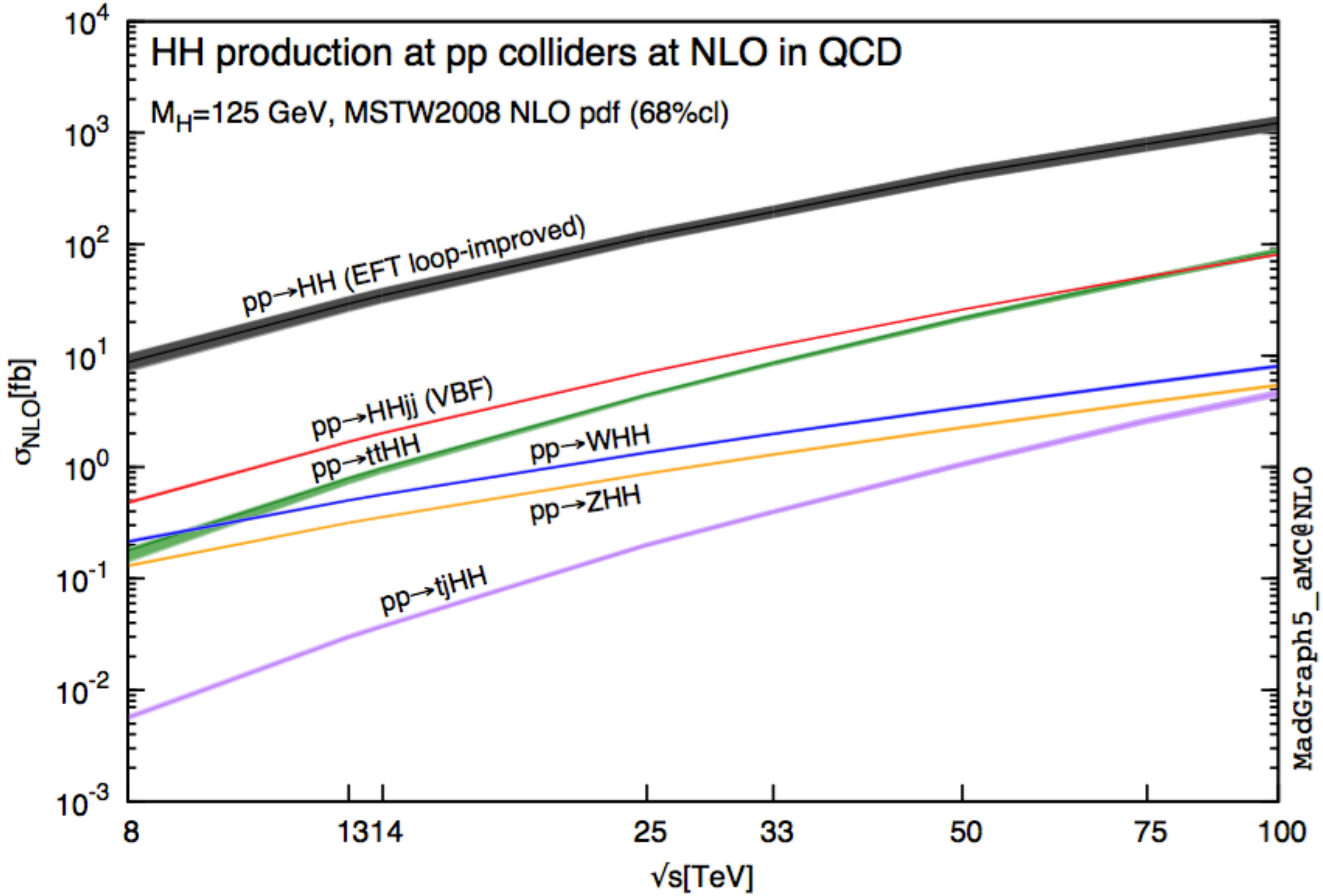
BACKUP SLIDES

ITk layout



Disc s
Strips x 7
(z=1415mm,1582mm,1800mm,
2040mm, 2320mm,2620mm,3000mm)
Long (47.8mm)
Strips x 2
(r=762mm, 1000mm)
Stub
Layer x 1 (r=862mm)
eta = 0.0
eta = 1.0
eta = 2.0
eta = 3.0
eta = 4.0
eta = 5.0
Pixel Barrel x 4
(r=39mm,78mm,155mm,
250mm)
Short (23.8mm)
Strips x 3
(r=405mm,519mm,
631mm)
Pixel Discs x 12
877mm,1059mm, 1209mm, 1358mm,
1509mm,1675mm,1875mm, 2075mm,
2275mm,2500mm,2750mm,3000mm
2.0
1.5
1.0
0.5
0.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

Higgs Pair production channels



[Frederix et al ` 14]

SUSY discovery potential with MVA