Projected sensitivity of Higgs boson pair production combining the $b\bar{b}\tau\tau$ and $b\bar{b}\gamma\gamma$ decay channels at the HL-LHC with the ATLAS detector

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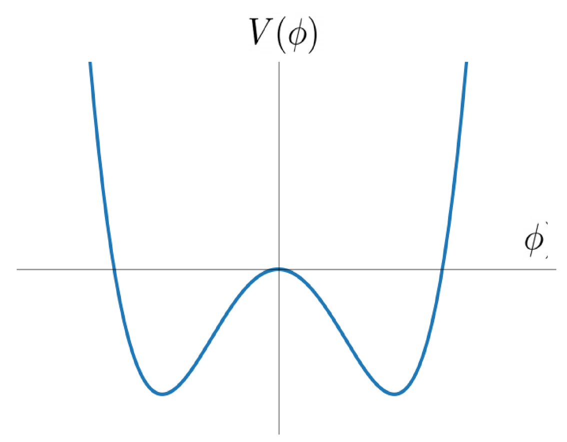
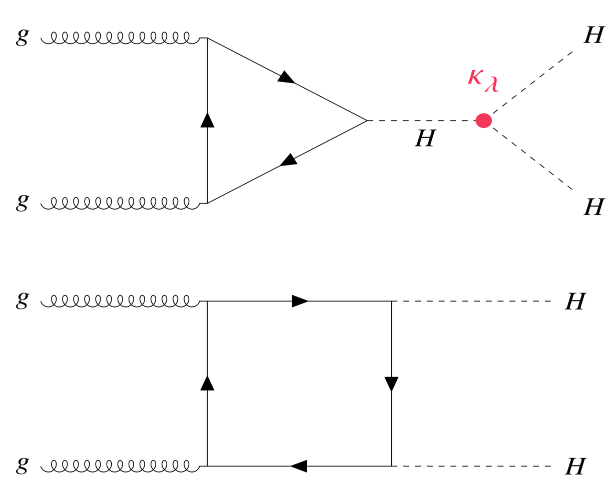
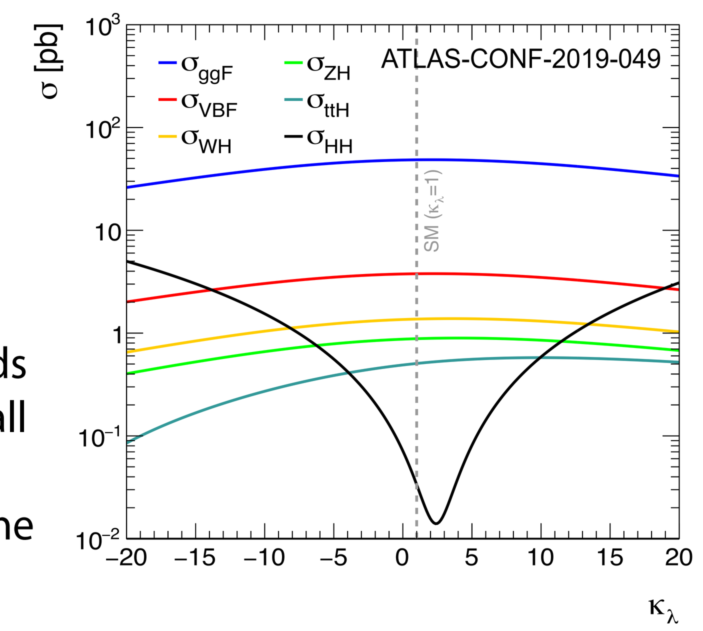
Motivation for HH Searches

Higgs boson pair production (HH) is the only direct way to probe the Higgs self-coupling at the LHC. The Higgs self-coupling is a key parameter for understanding the mechanism of electroweak symmetry breaking, but it has yet to be experimentally measured.



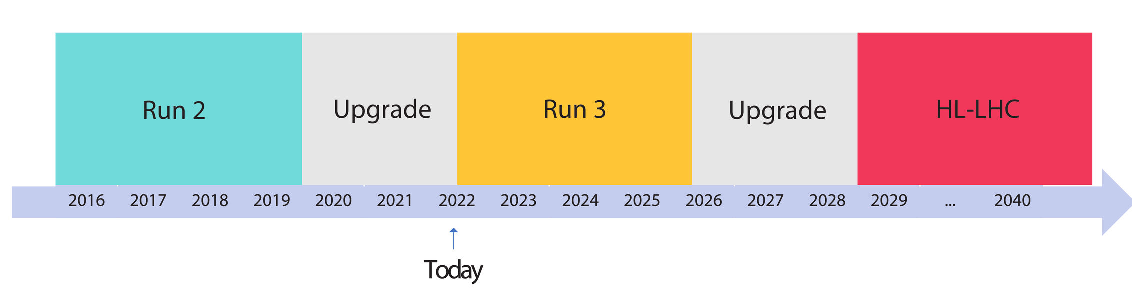




In the Standard Model (SM) HH production proceeds through gluon-gluon fusion with a very small overall cross-section of 31 fb^{-1} at 13 TeV. However, the HH cross-section is extremely sensitive to changes to the Higgs self-coupling.

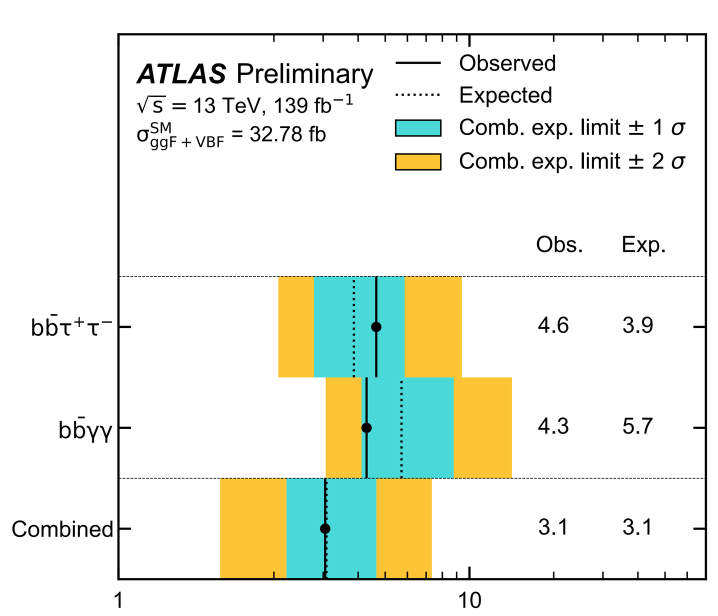
HH at the HL-LHC

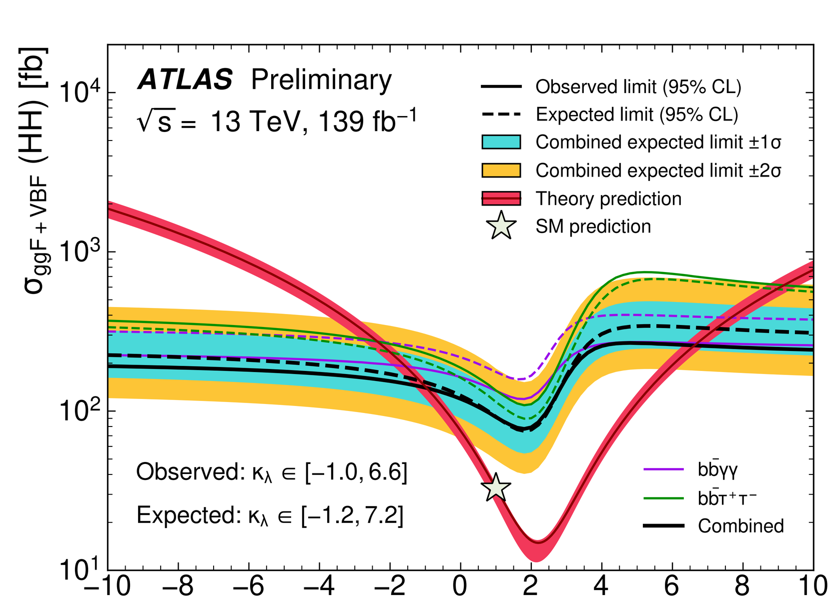
The upgrade to the High Luminosity LHC (HL-LHC) will allow us to collect data at a faster rate than ever before. The expected total integrated luminosity at HL-LHC is 3000 fb^{-1} at 14 TeV. This dataset will be 21x larger than the 139 fb^{-1} collected during Run 2.



Full Run 2 Combination of $b\bar{b}\tau\tau$ and $b\bar{b}\gamma\gamma$ Decay Channels

A combination of the Full Run 2 results in the $b\bar{b}\tau\tau$ and $b\bar{b}\gamma\gamma$ decay channels with 139 fb^{-1} was performed in 2021. As no excess was observed, limits on SM HH production were set at 3.1xSM. The Higgs self coupling (κ_λ) was constrained to between [1.0,6.6] (observed).





For more details on the Run 2 combinaton see: ATLAS-CONF-2021-052

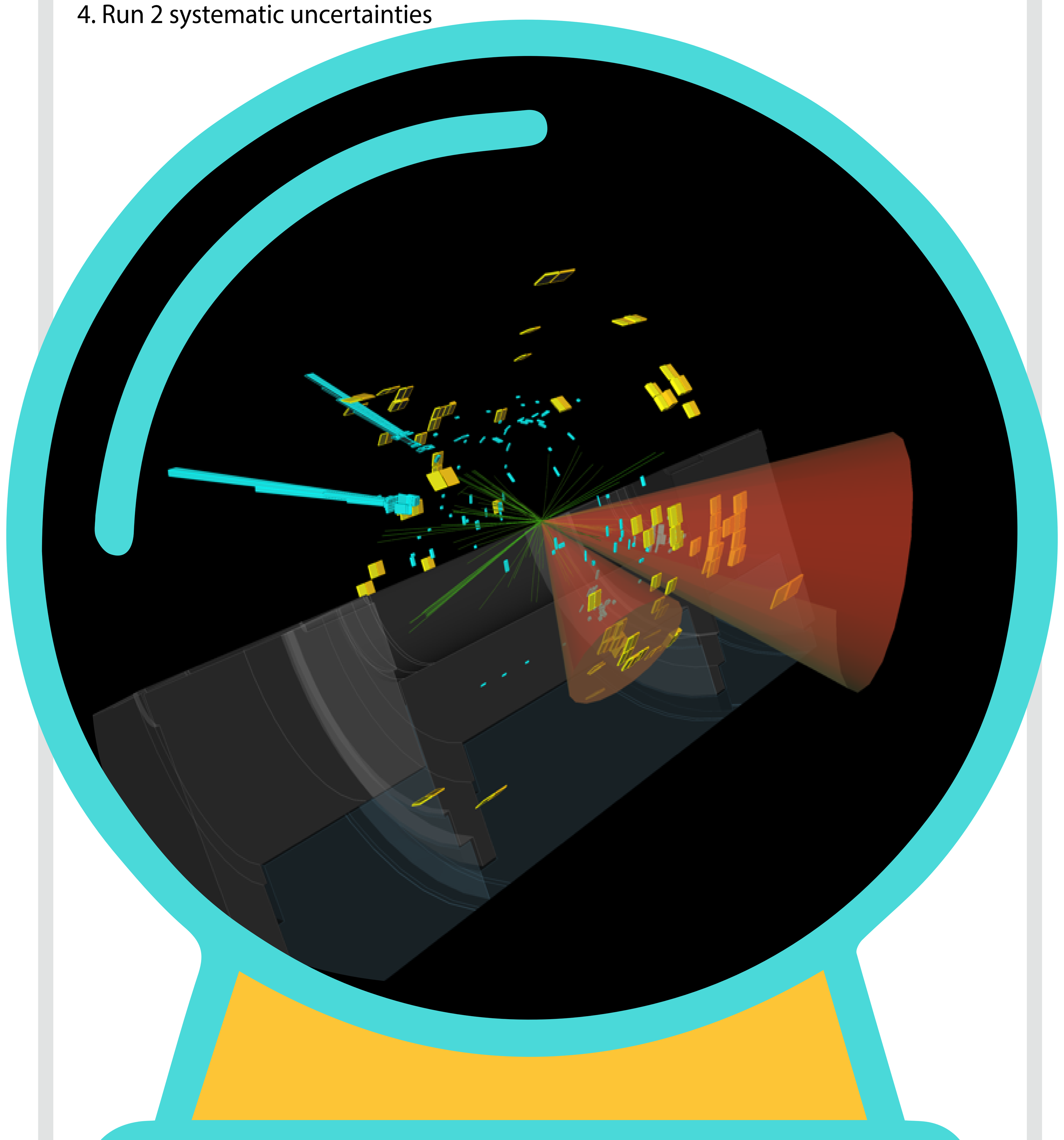
HL-LHC Projection Strategy

To extrapolate from the Run 2 results obtained with 139fb-1 of data at 13 TeV, first the total integrated luminosity is scaled to 3000 fb^{-1}. Next, the cross-sections for individual processes are scaled to adjust from 13 to 14 TeV. No changes to object identification efficiencies, trigger or analysis strategy are assumed, other than the systematic uncertainties, which are scaled as follows:

Statistical Uncertainties	$\propto 1/\sqrt{L}$
Experimental Uncertainties	$\propto 1/\sqrt{L}$ Until floor reached
Theoretical Uncertainties	x 0.5

Scaling of systematic uncertainties in the baseline scenario

To provide an envelope for interpreting the results, four systematic uncertainty scenarios were explored:
1. No systematic uncertainties
2. Baseline - Experimental uncertainties scaled, and theory uncertainties halved
3. Theory uncertainties halved – but with Run 2 experimental systematic uncertainties
4. Run 2 systematic uncertainties



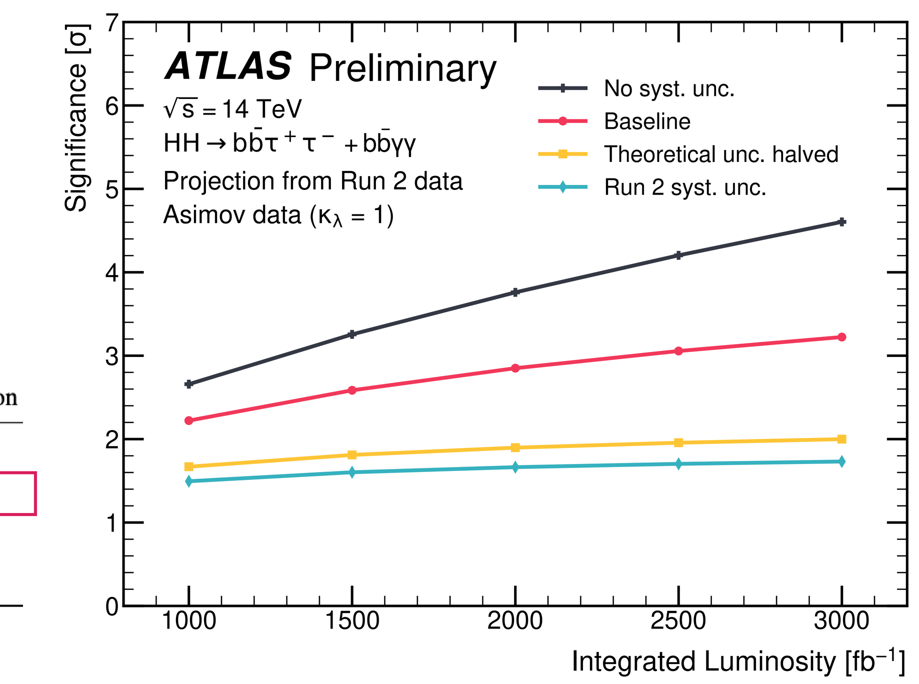
A candidate HH bbγγ event in the ATLAS detector

Results

SM HH at 3.2σ with just two channels

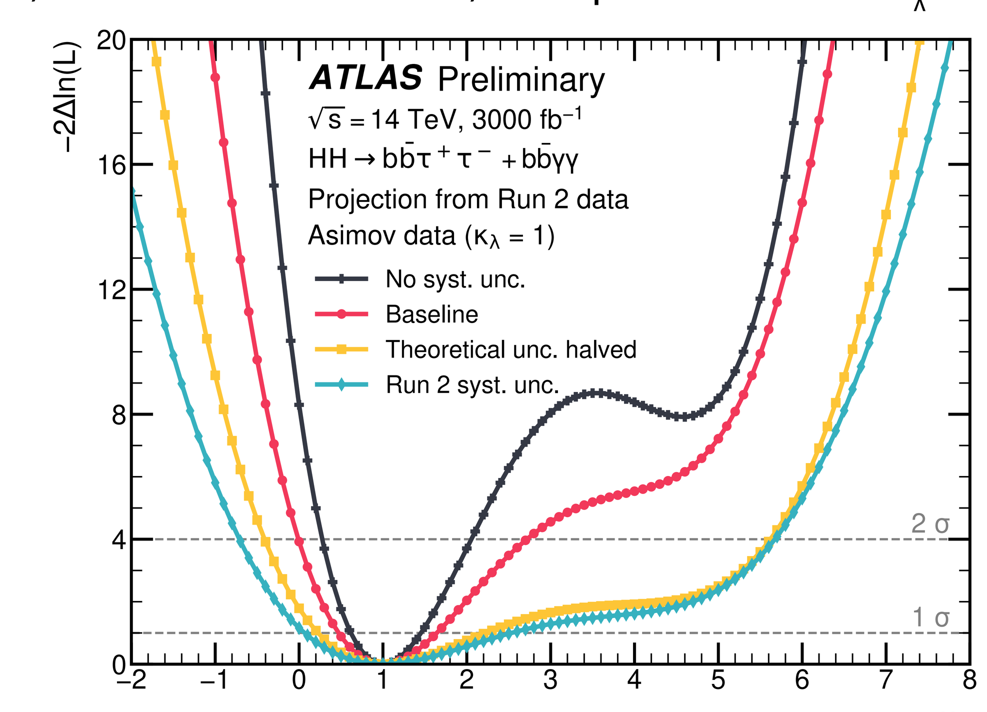
If SM HH production is observed, we expect to achieve a significance of 3.2σ in the baseline scenario at 3000 fb^{-1}. Other scenarios are detailed in the table below.

Uncertainty scenario	Significance $b\bar{b}\gamma\gamma$	$b\bar{b}\tau^+\tau^-$	Combination
No systematic uncertainties	2.3	4.0	4.6
Baseline	2.2	2.8	3.2
Theory uncertainties halved	1.1	1.7	2.0
Run-2 systematic uncertainties	1.1	1.5	1.7



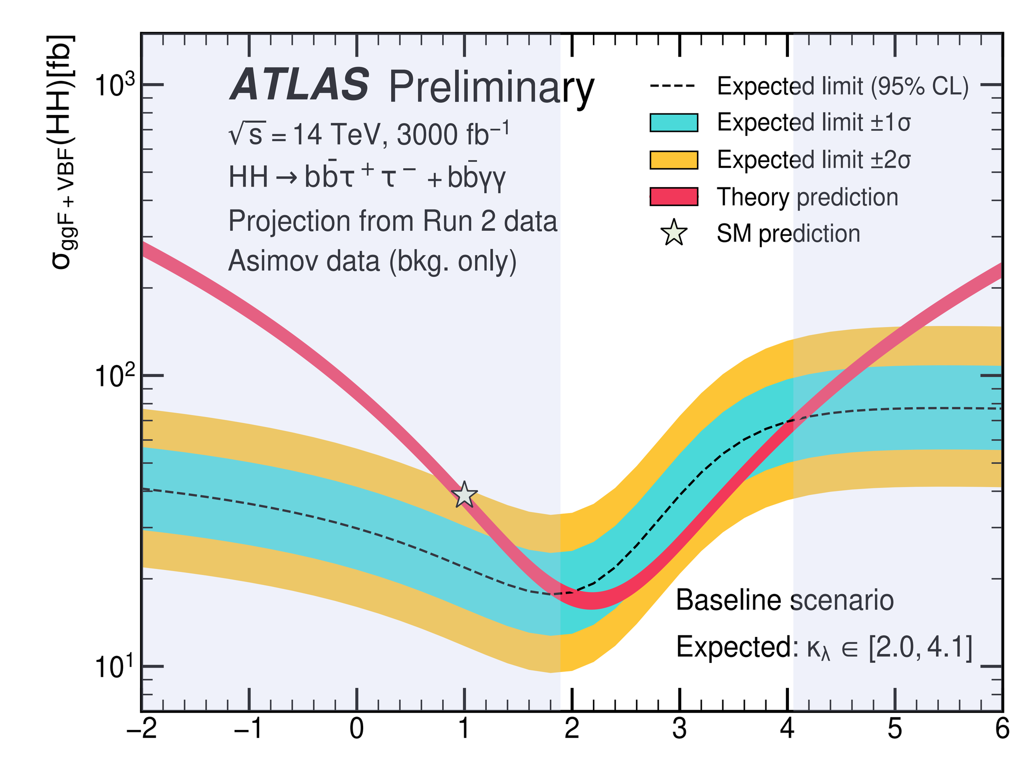
Measure κ_λ with close to 50% precision

If SM HH production is observed, we can use it to put constraints on κ_λ. With the current analysis strategies, in the baseline scenario, we expect to measure κ_λ between [0.5, 1.6] at 1σ CI.



Possibility of excluding κ_λ=1

If the current $b\bar{b}\tau\tau$ and $b\bar{b}\gamma\gamma$ analysis strategies are extrapolated to the HL-LHC and no HH production is observed, it could mean that κ_λ lies somewhere between [2.0, 4.1].



For more details on the combined projection see: ATL-PHYS-PUB-2022-005