Boosted VBF HH→4b
HL-LHC projections

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The Outline

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2. The extrapolations for the HL-LHC
3. Studying the HH->4b boosted VBF channel
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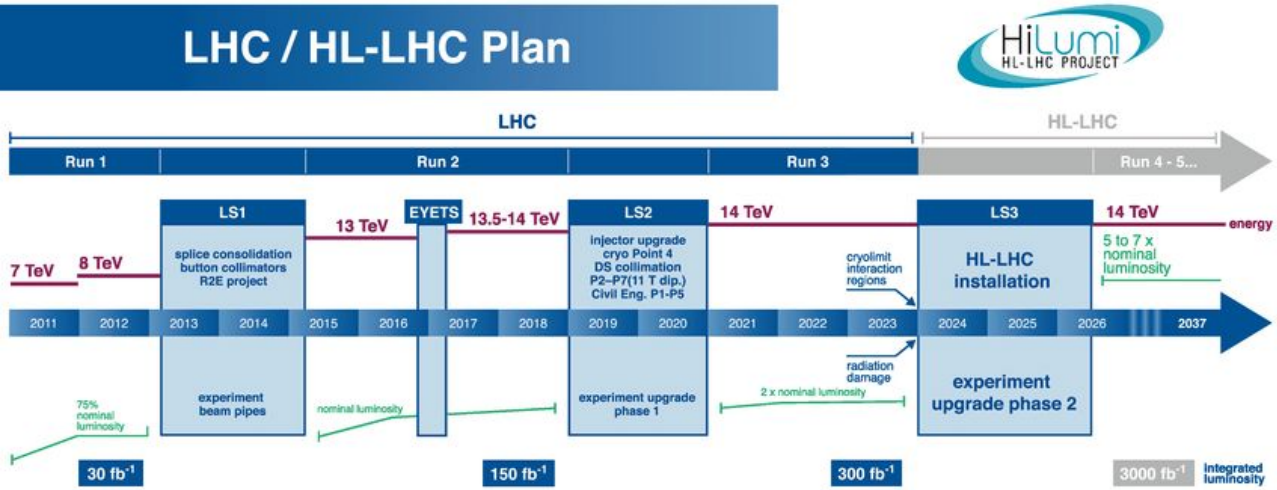
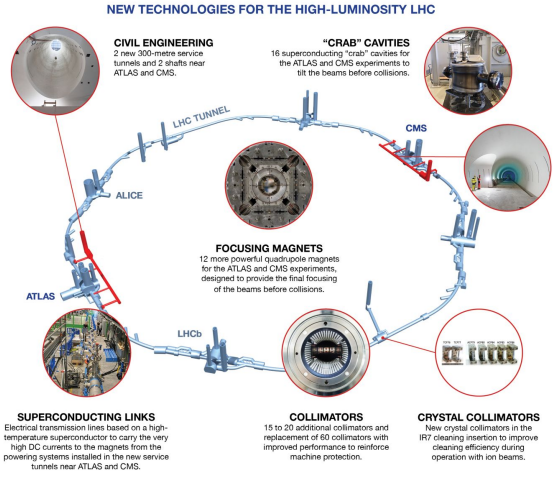




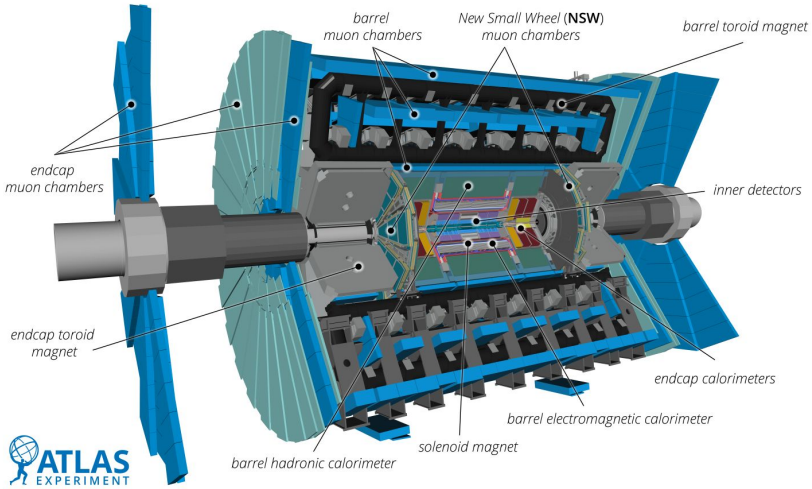
Darnajou, Mathieu. (2017). Development of the Pixel Detector for the ATLAS Detector Upgrade.

" **The High-Luminosity Large Hadron Collider** (HL-LHC) project aims to crank up the performance of the LHC in order to increase the potential for discoveries after 2030. The objective is to increase the integrated luminosity by a factor of 10 beyond the LHC's design value."

Some other considerations have to be made in order to account for this increase in the luminosity

Introduction

The Luminosity is a critical performance metric for accelerators, proportional to collision frequency; higher luminosity enables more data collection and the study of rare processes that are dependent of the statistical power.

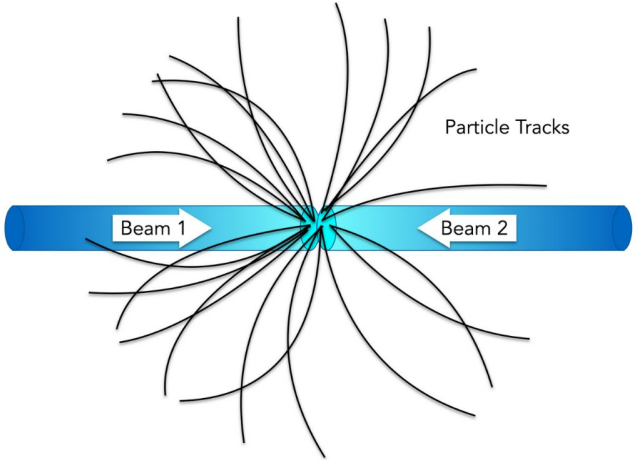


High-Luminosity LHC (HL-LHC):

- Operational by **2029**.
- Will produce **15M Higgs bosons/year** (vs. 3M in 2017).
- Enables detailed studies of known mechanisms (e.g., Higgs boson) and rare phenomena.

Announced as the top priority of the **2013 European Strategy for Particle Physics**.

The extrapolation for the HL-LHC



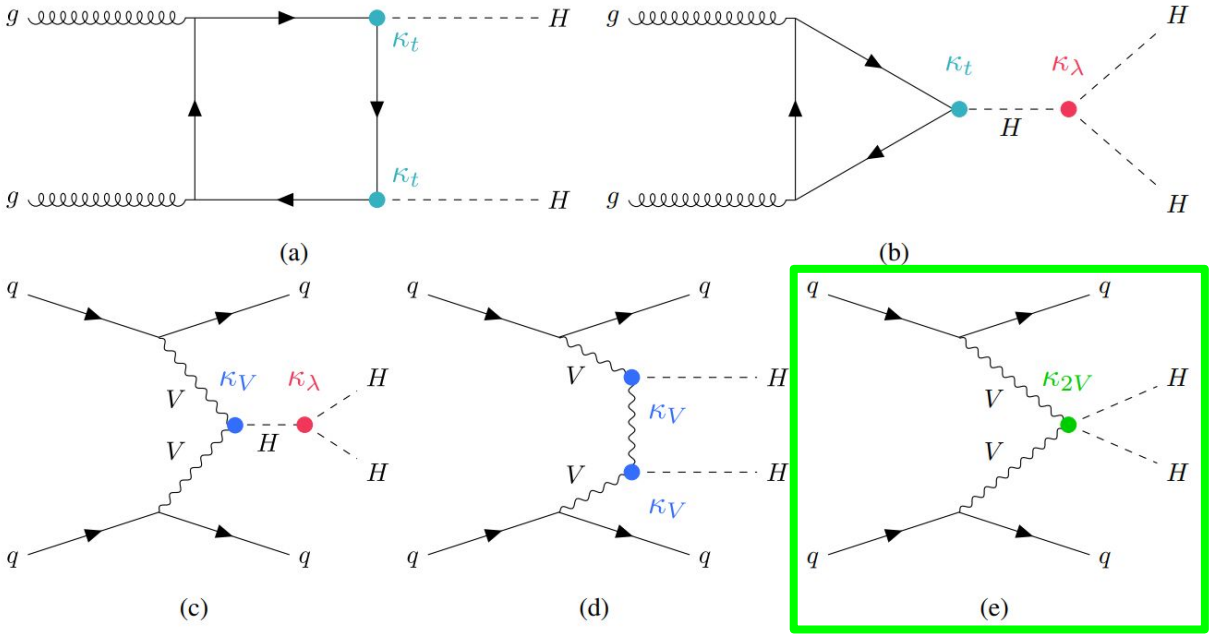
The parameters we are working with:

- The expected maximum integrated **luminosity** reachable for the accelerator will be 3000 fb^{-1}. The improvement is huge considering the current 140 fb^{-2} integrated luminosity of the Run 2.
- Along with the increase in luminosity, there will be an increase in the center-of-mass energy from 13 TeV to 14 TeV, which will affect the production cross sections of multiple processes.

In order to cope with the high radiation damage and contamination from simultaneous *p p* collisions (pileup), the ATLAS experiment is planning several upgrades of its sub-detectors and trigger system

Studying the HH->4b boosted VBF process

HH production has yet to be observed at the LHC due to its low production cross-section, approximately 1000 times smaller than the single Higgs boson production.



$$\kappa_{2V} = g_{HHVV}/g^{\mathrm{SM}}_{HHVV}$$

$$\kappa_\lambda = \lambda_{HHH}/\lambda^{\mathrm{SM}}_{HHH}$$

$$\sigma^{\mathrm{SM}}_{\mathrm{ggF}} = 31.1^{+2.1}_{-7.2}\ \mathrm{fb}$$

$$\sigma^{\mathrm{SM}}_{\mathrm{VBF}} = 1.73 \pm 0.04\ \mathrm{fb}$$

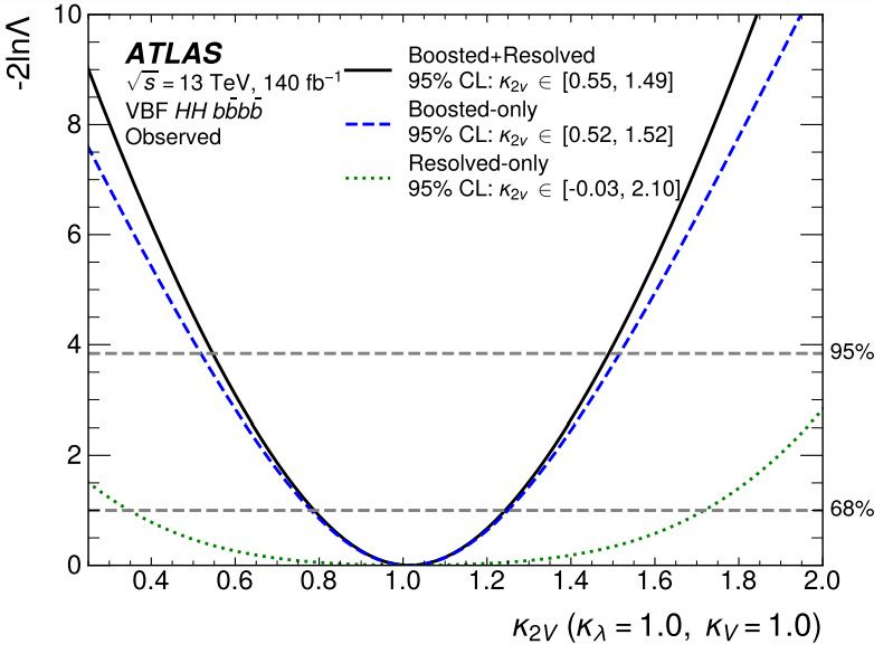
The VBF production cross-section depends critically on the value of the modifier κ_{2V}

Studying the HH->4b boosted VBF process

The Run 2 Legacy results can be found here (CDS)
Overall goal → Extrapolate di-Higgs constraints within the future HL-LHC

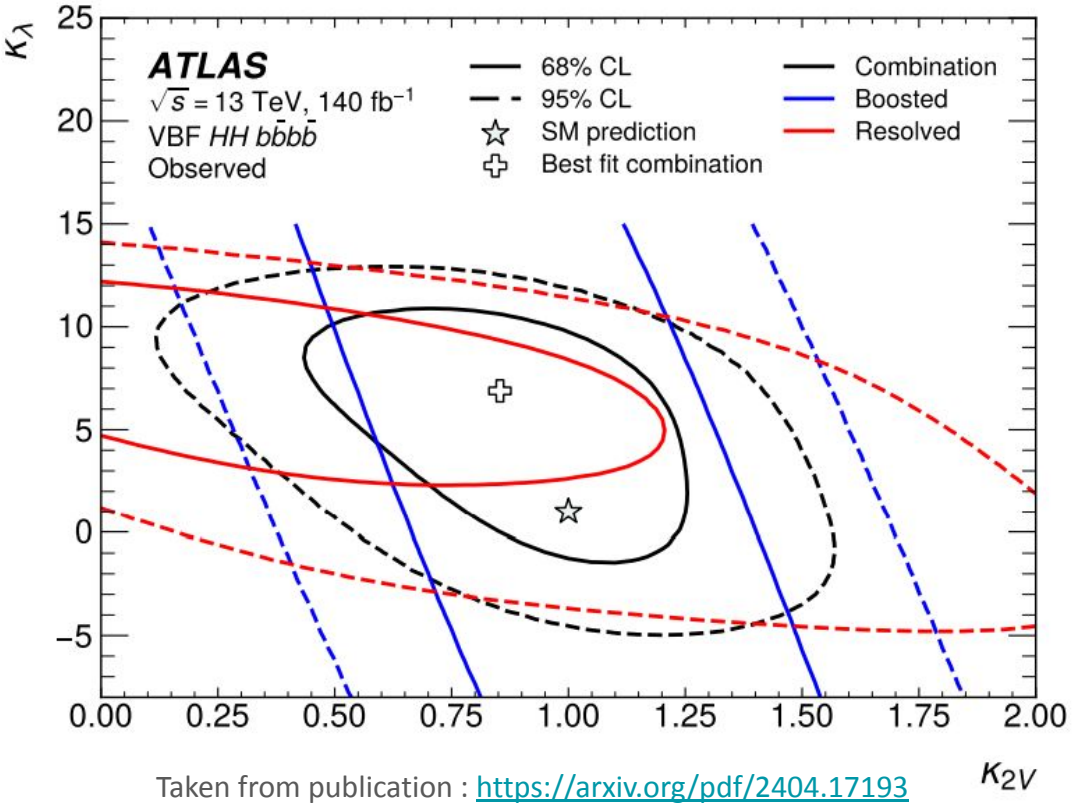
- Focus on $\kappa 2V$ coupling modifier
- Previous studies have managed to restrict the value through analysis: 140 fb^{-1} of data, pp collisions at 13 TeV (ATLAS detector, LHC)
- Importance of Boosted topology: Improves sensitivity to anomalous $\kappa 2V$ values
- Higgs pair production via Boosted VBF as a promising channel to further restrict the coupling values

Taken from publication : https://arxiv.org/pdf/2404.17193



The aim is to study how these $\kappa 2V$ constraints will behave for higher center-of-mass energy and integrated luminosity

Previous studies on Boosted VBF



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The VBF HH production mode is sensitive to both $\kappa\lambda$ and $\kappa 2V$

The $\kappa\lambda$ sensitivity is driven by the resolved analysis, while the $\kappa 2V$ sensitivity is dominated by the boosted analysis.

How the extrapolations are made

We will scale, MC signal, background, and systematic uncertainties under some general requirements:

To extrapolate, it is necessary to start from the previous results of Run 2.

1. An increase in the amount of data (distributions size) corresponding to the luminosity increase must be taken into account. Different luminosity values are considered to make a complete study.
2. A ***scale factor*** is applied to take into account the increase in center-of-mass energy from $\sqrt{s}$ = 13 TeV to $\sqrt{s}$ = 14 TeV.
3. The background should be increase according to the other considerations.

Four systematic uncertainty scenarios are proposed :

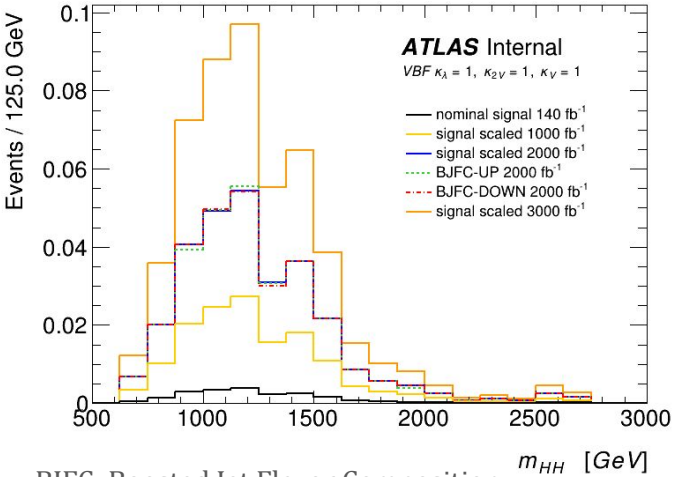
1. Only statistical uncertainties are considered (No syst. unc.).
2. A baseline scenario the expected improvements within the HL-LHC are considered.
3. A scenario where Run 2 experimental uncertainties are considered but theoretical uncertainties associated to *HH* signals are halved (Theoretical unc. halved)
4. A scenario with the same Run 2 experimental uncertainties (Run 2 syst. unc).

How the extrapolations are made

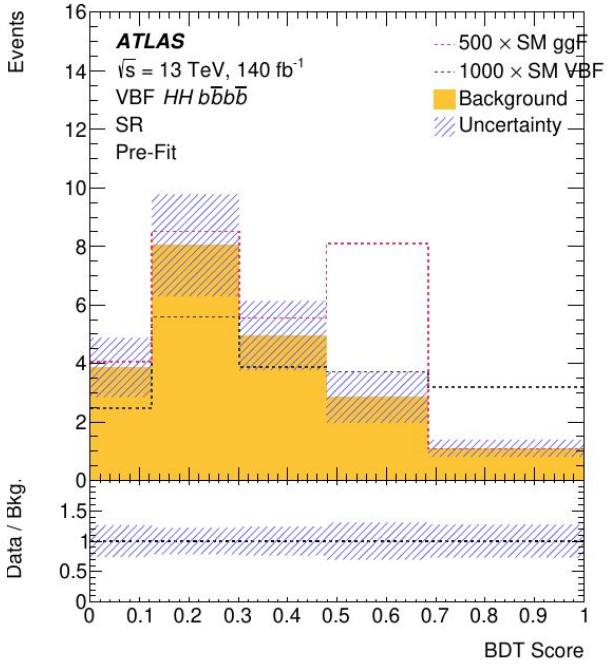
Changing the luminosity

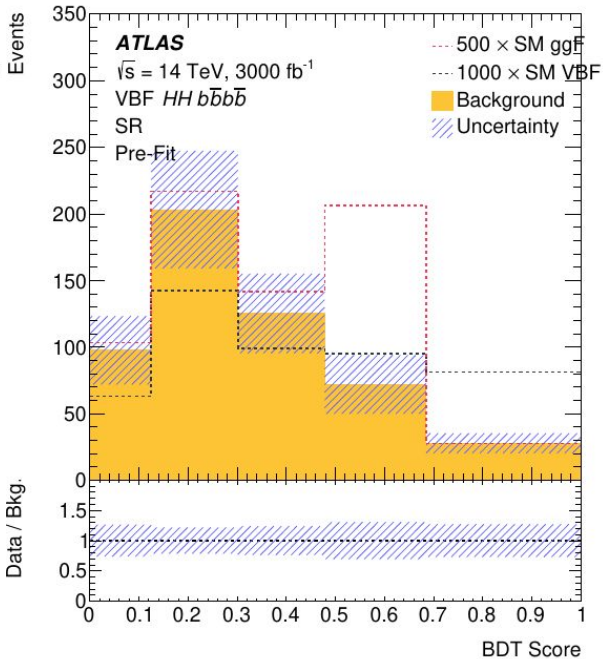
Everything, including the systematic uncertainties are being scaled according to the luminosity ratio

As sanity check, the signal distributions for HH mass were plotted in three different values of increased luminosity



BJFC: Boosted Jet Flavor Composition

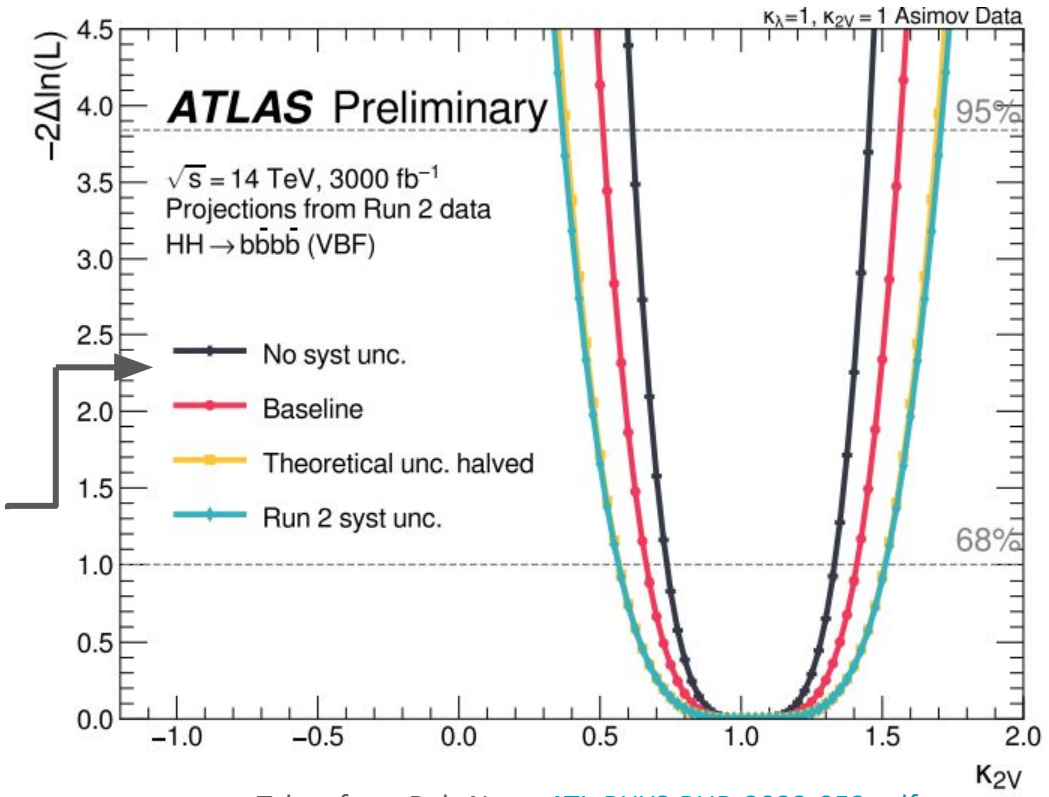




Plots and metrics to consider

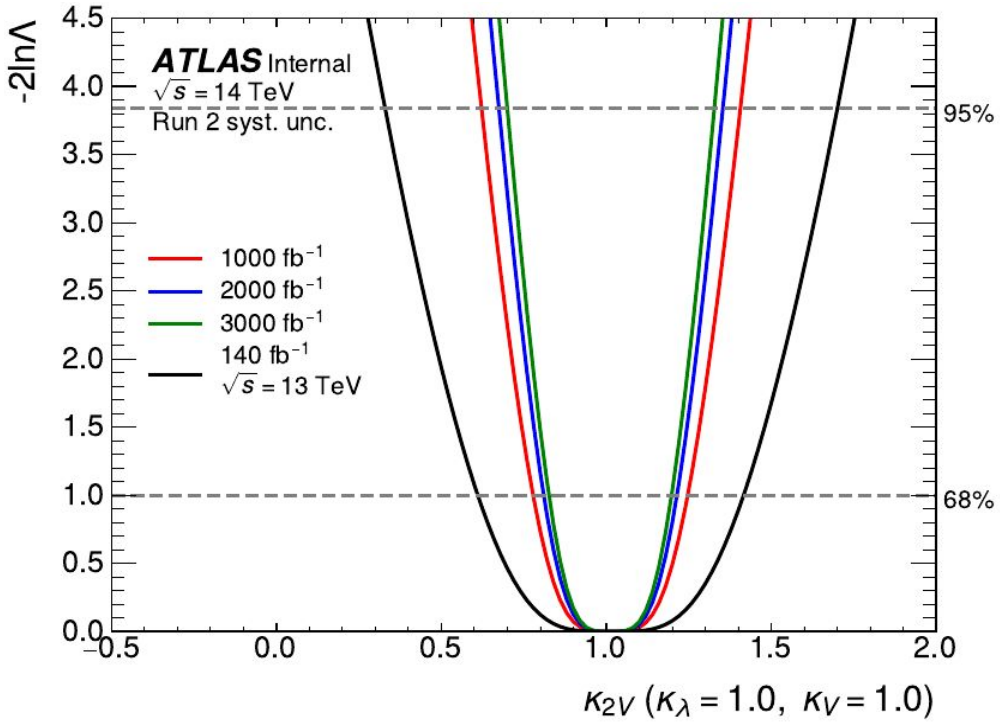
Profile likelihood scan for different $\kappa 2V$ values for the resolved Run 2 HH→4b analysis. It represents how much we can restrict the expected value of the modifier within our considerations.

We will keep the same uncertainties scenarios and will focus on extrapolation for the boosted 4b VBF analysis.



Taken from Pub-Note: ATL-PHYS-PUB-2022-053.pdf

Conclusions



- The HL-LHC project will provide significant technical and analytical capabilities in areas such as the study of Higgs boson coupling parameters.
- Determining the values of coupling modifiers in di-Higgs systems could refine our understanding of phenomena such as the electroweak symmetry-breaking mechanism or the validation of theories beyond the Standard Model.
- The Boosted VBF production mode for the HH → 4b system represents a valuable approach to constrain the value of $\kappa 2V$.
- The luminosity and center-of-mass energy prospects of the HL-LHC are promising for improving the estimates of this value without the need to resort to new techniques.

References

1. Atl-Phys-pub-2018-053.PDF. Available at: https://cds.cern.ch/record/2652727/files/ATL-PHYS-PUB-2018-053.pdf .
2. Search for pair production of boosted Higgs bosons via vector-boson fusion in the 4b final state using pp collisions at 13 TeV with the ATLAS detector. ATLAS Collaboration, November 2024.
3. The High Luminosity Large Hadron Collider, https://home.cern/science/accelerators/high-luminosity-lhc
4. Darnajou, Mathieu. (2017). Development of the Pixel Detector for the ATLAS Detector Upgrade.

Thank you!