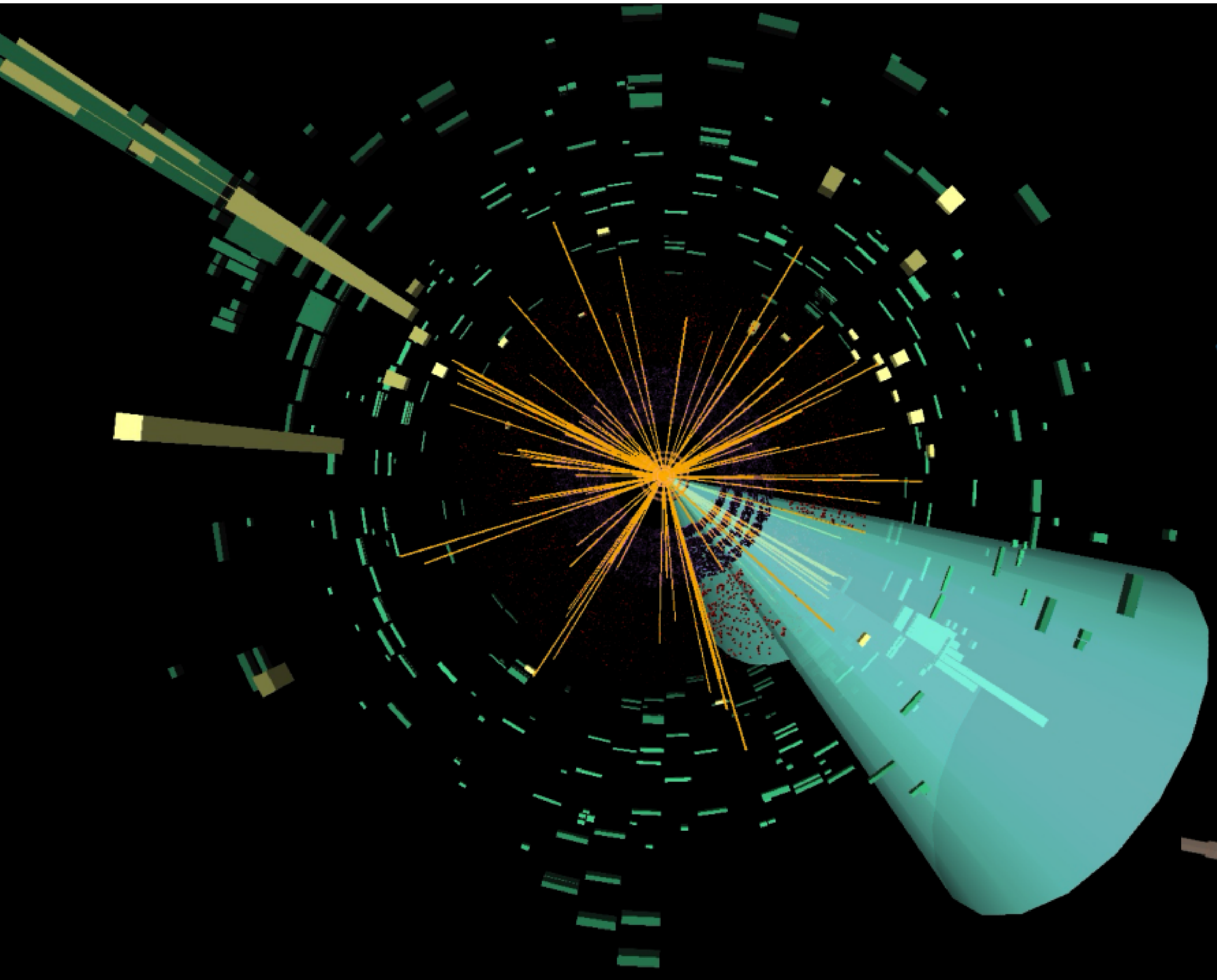
$HH \rightarrow b\bar{b}\gamma\gamma$

Alexandra Sidley

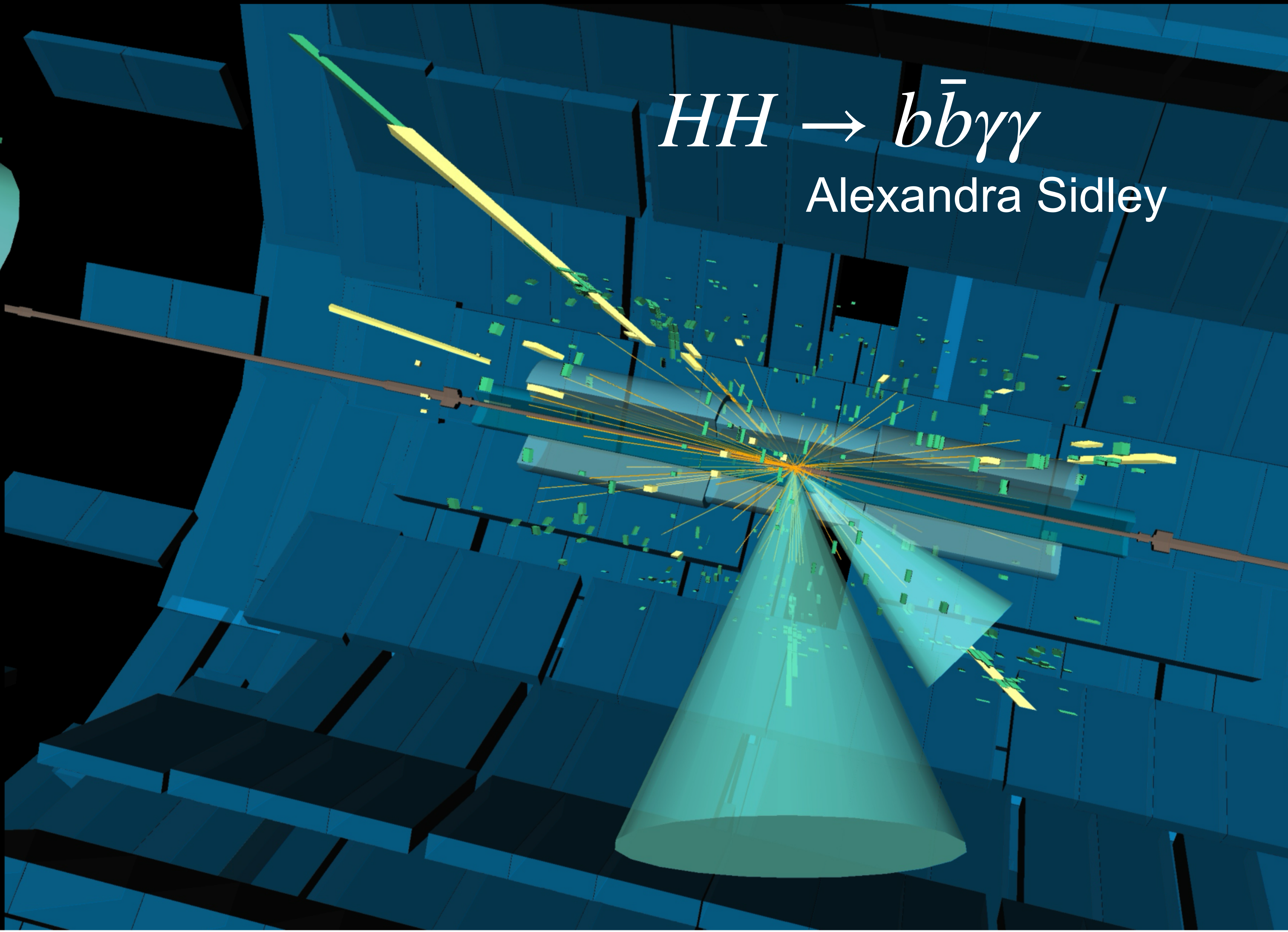


ATLAS EXPERIMENT

Run: 482747

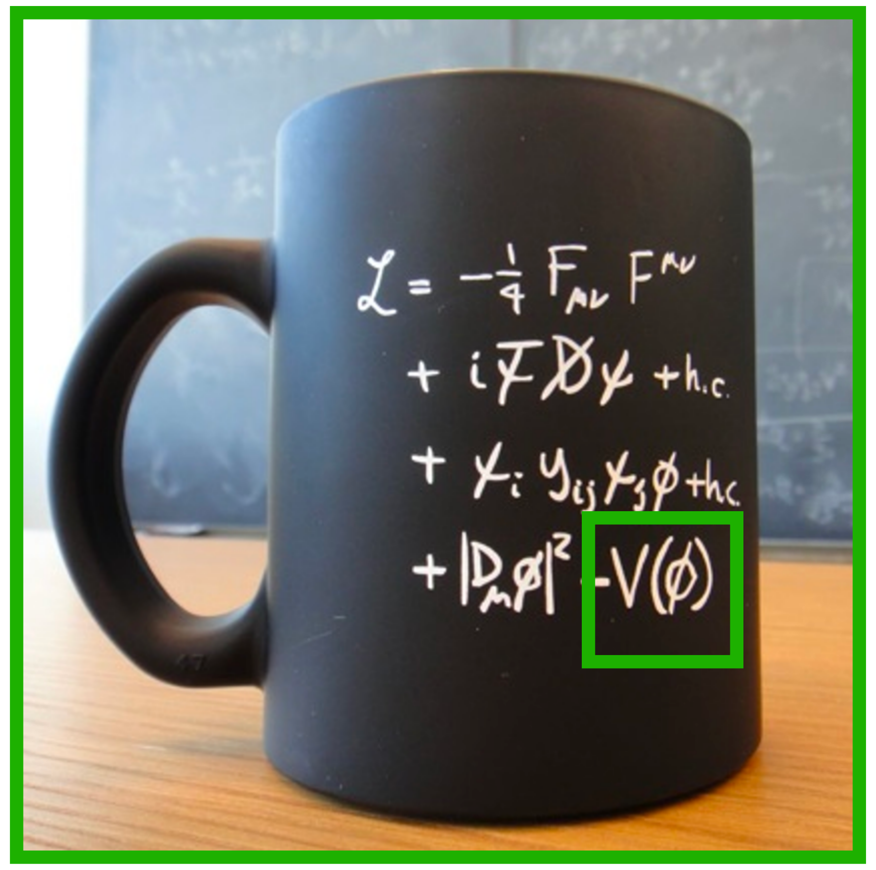
Event: 990703589

2024-08-17 15:42:18 CEST



Why are we interested in di-Higgs?

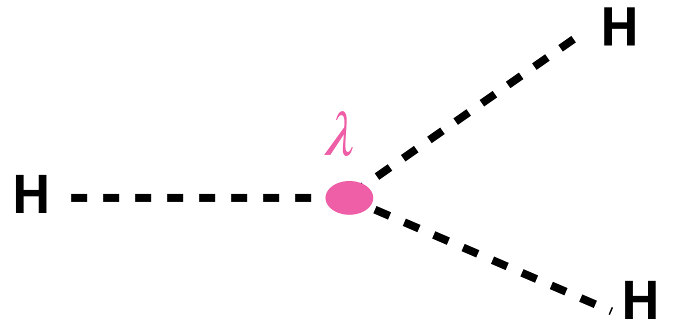
Studying the **Higgs potential** is one of our primary physics goals

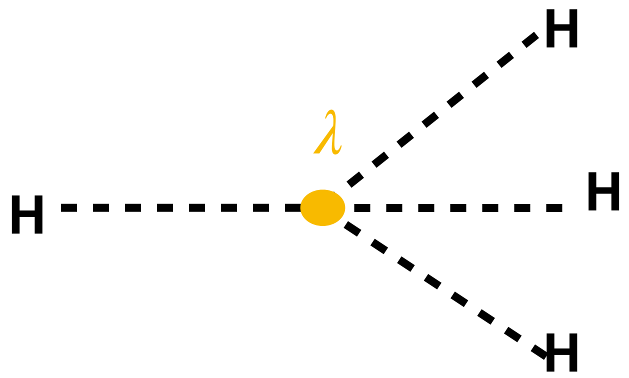


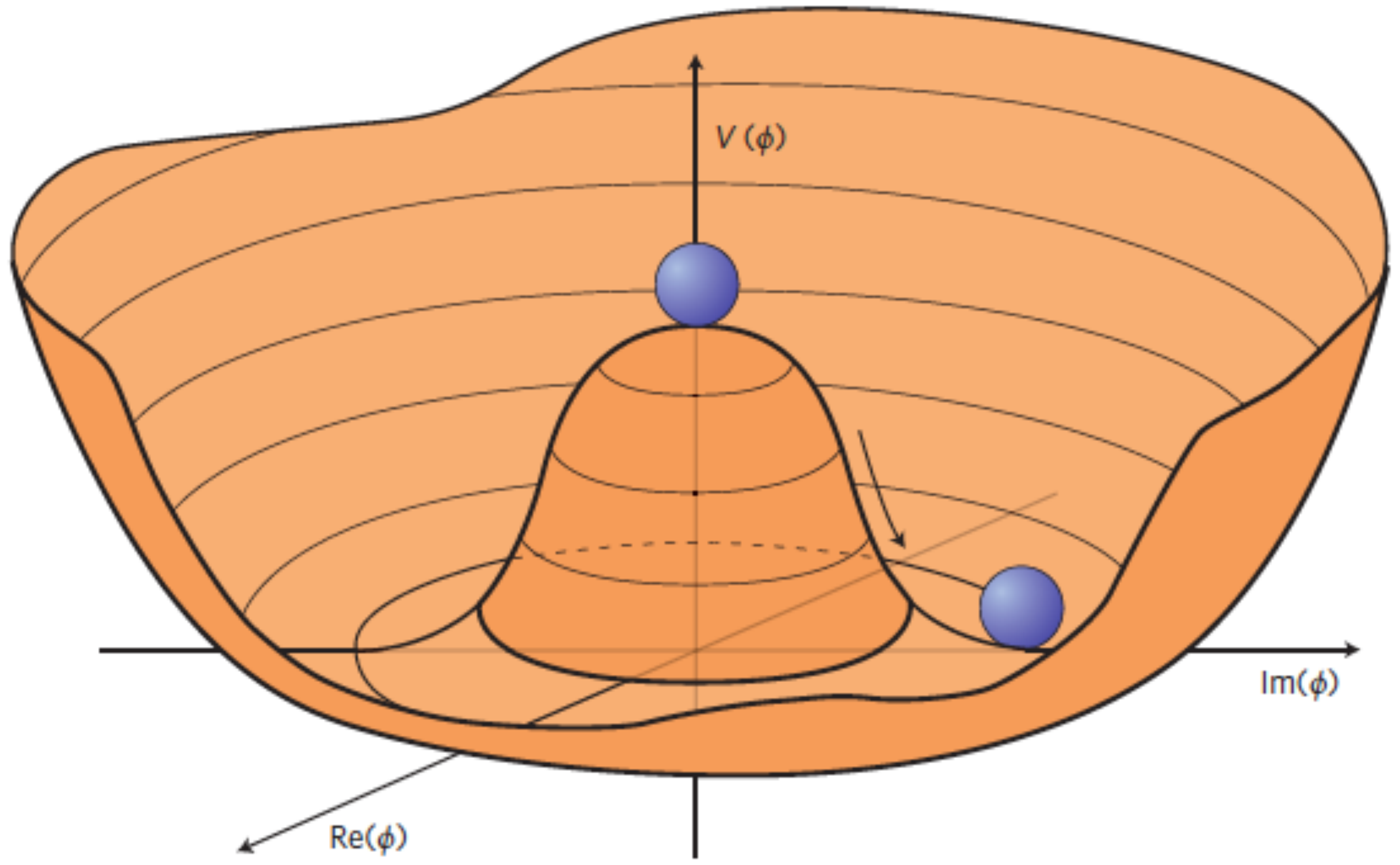
$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda v H^3 + \lambda H^4$$

Mass term

3 and 4 point interactions



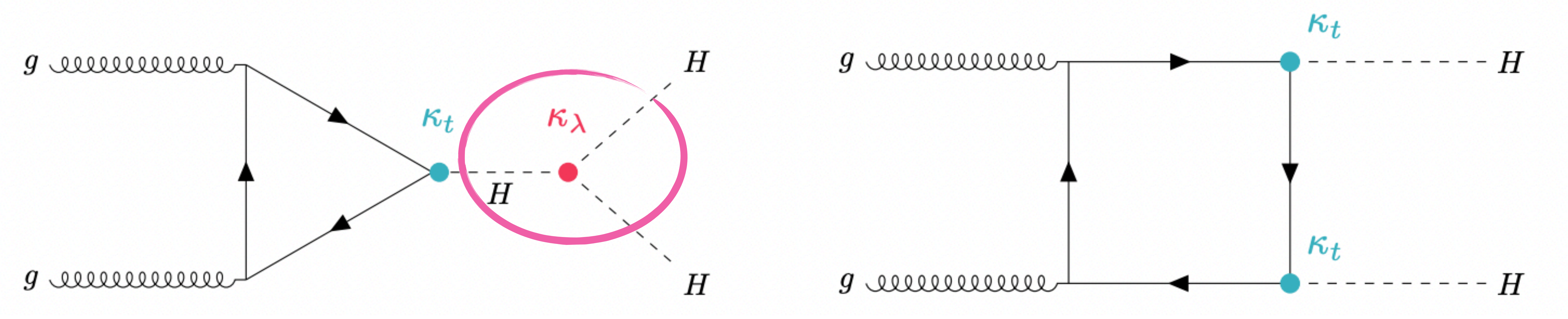




Di-Higgs in ATLAS

How do we measure the Higgs self-coupling in ATLAS?

Search for **di-Higgs** processes (2 Higgs bosons)



Di-Higgs in ATLAS

Primary Di-Higgs **decay modes**

Clean signature

Large branching ratio

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

Golden channels:

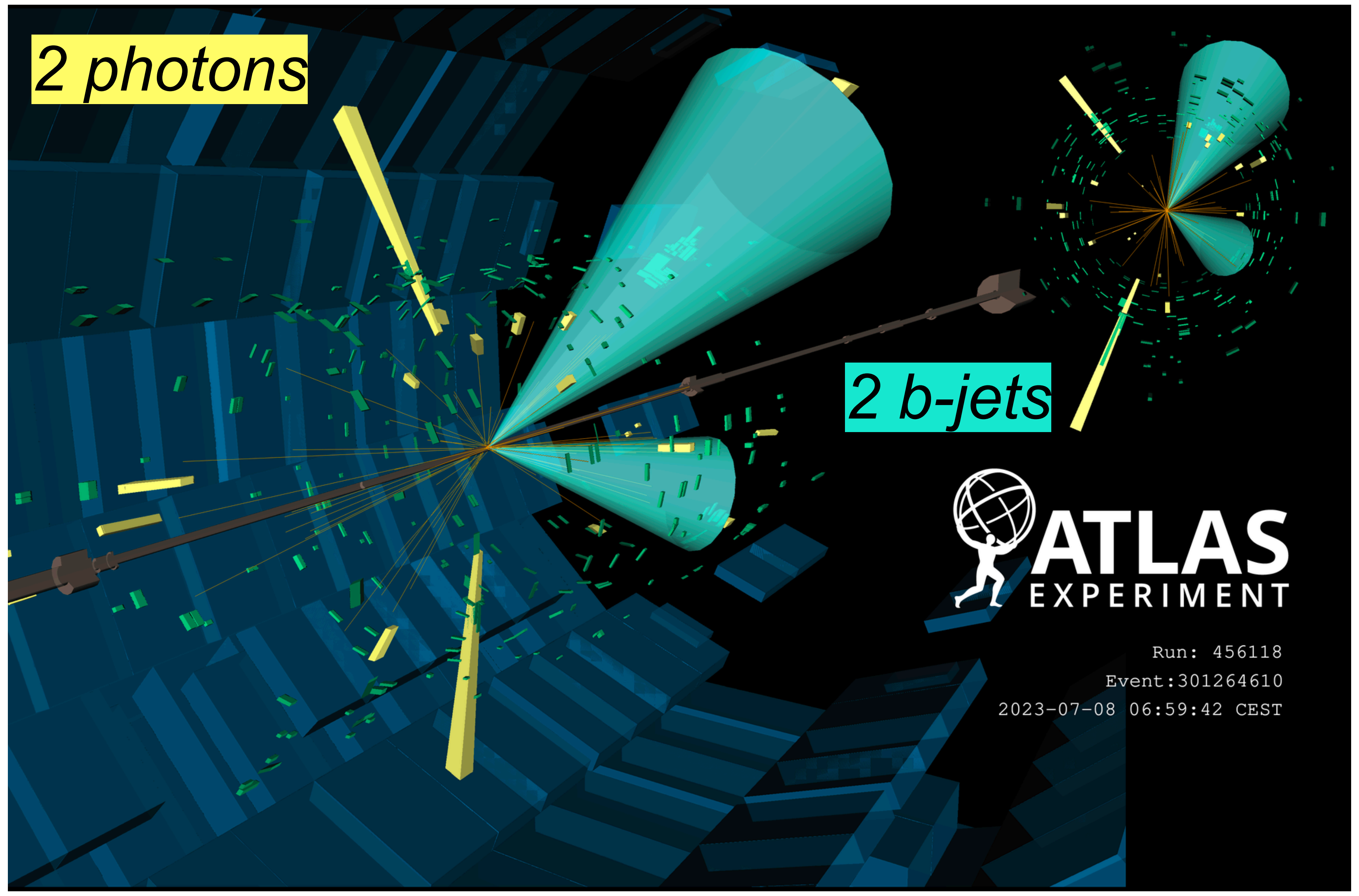
$\underline{HH \rightarrow b\bar{b}\gamma\gamma}$

$HH \rightarrow b\bar{b}b\bar{b}$

$HH \rightarrow b\bar{b}\tau\tau$

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

Using ATLAS Run 2 and Run 3 (2022-2024) data for the **first time** ($140fb^{-1} \to 308fb^{-1}$)



A $HH \to \bar{b}b\gamma\gamma$ candidate event

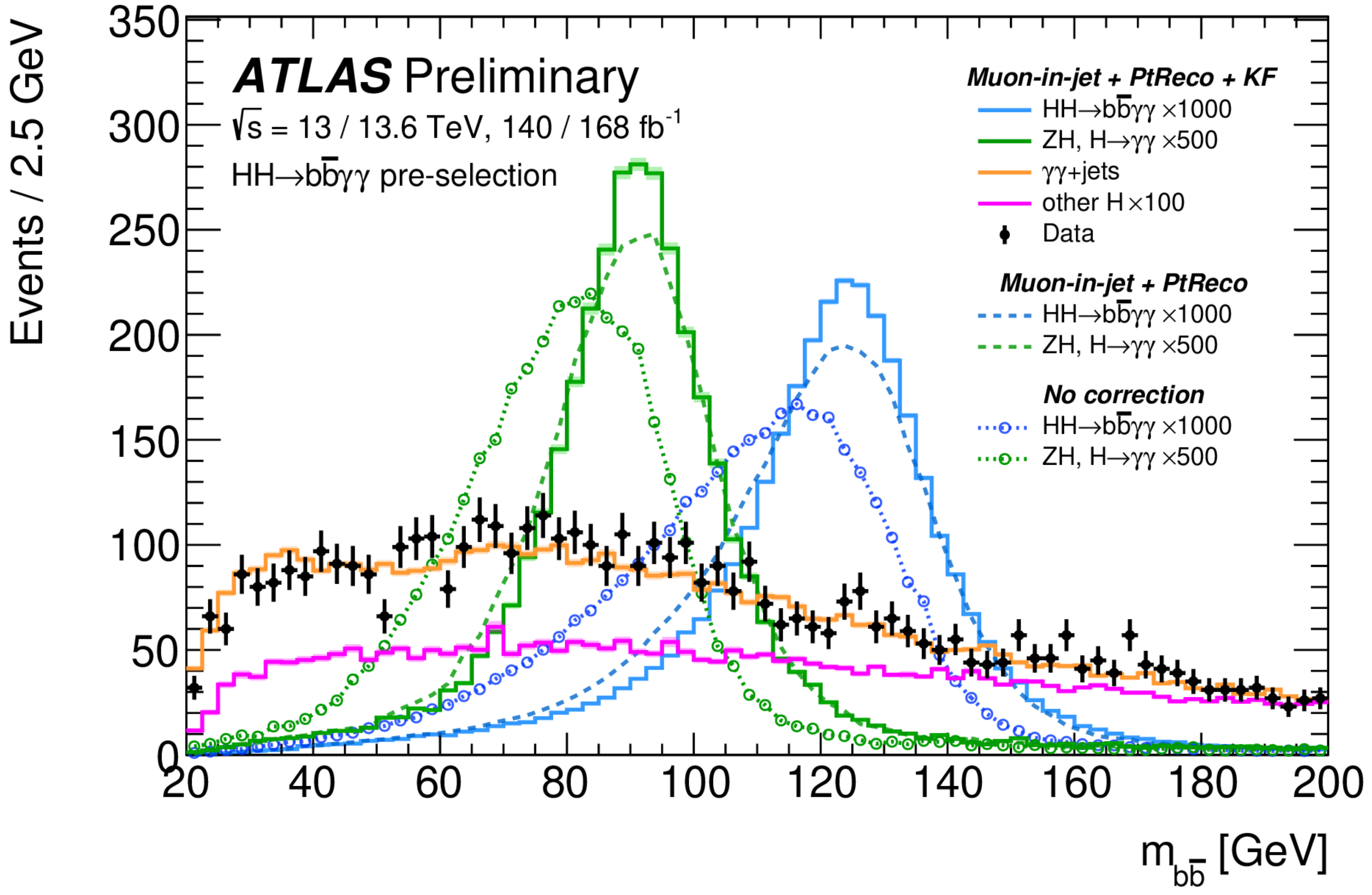
- Reconstruct 2 photons and 2 b-jets
- Fit the invariant mass of the photons $m_{\gamma\gamma}$ to extract HH signal

Public result: ATLAS-CONF-2025-005

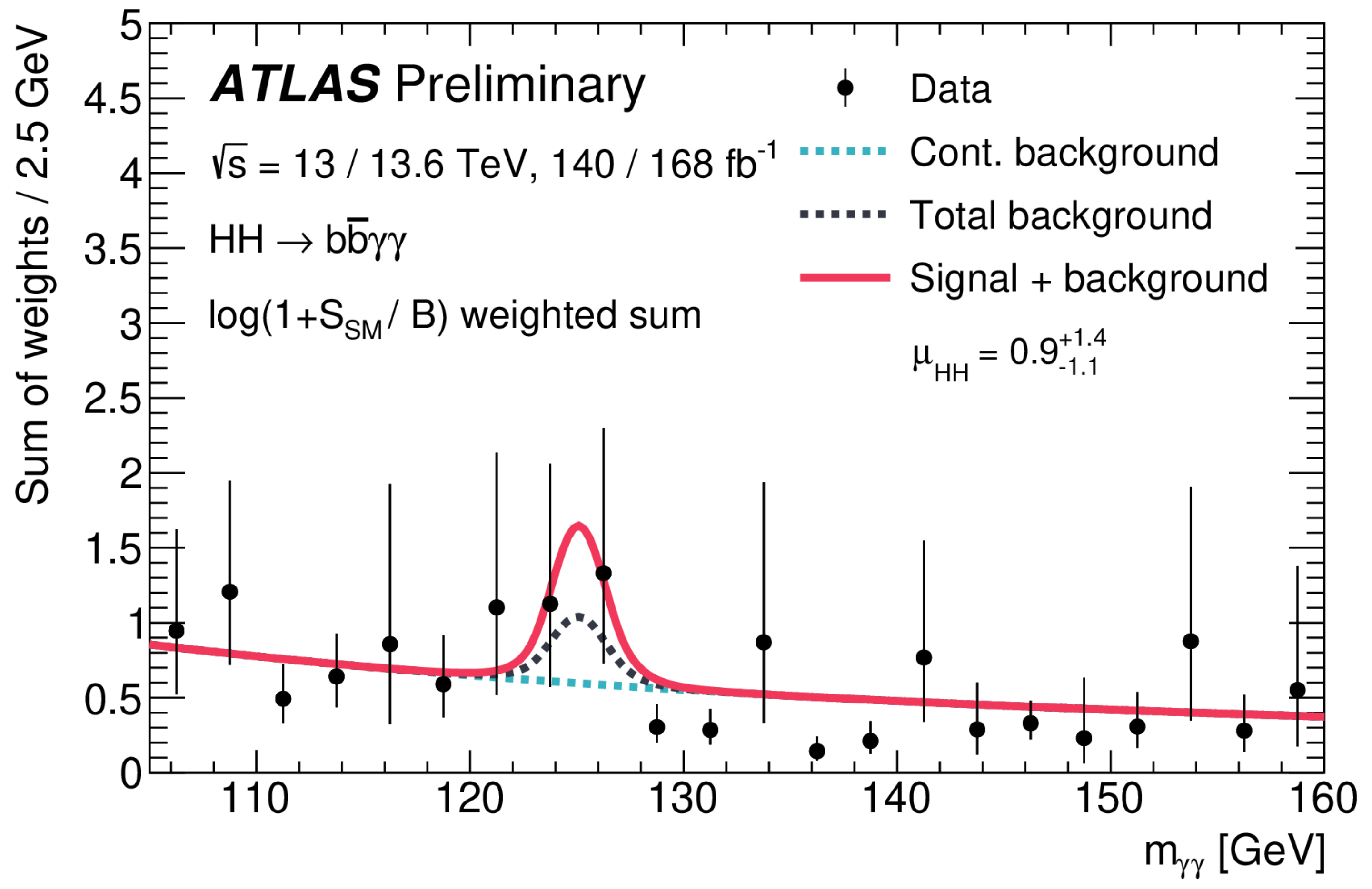
$HH \rightarrow \bar{b}b\gamma\gamma$

What's new and how much did we gain?

- Inclusion of 2022-2024 Run 3 data! (~50%)
- New b-jet tagging algorithm based on GNN (~20%)
- Category optimisation (~10%)
- Kinematic fit to improve di-jet mass resolution (~5%)



$HH \to \bar{b}b\gamma\gamma$: results



di-Higgs signal strength extracted from fit to $m_{\gamma\gamma}$

Observed HH signal strength:

μ_{HH} = $0.9^{+1.4}_{-1.1}$ times the SM

HH SM discovery significance:

1.0σ expected, 0.8σ observed

Higgs self-coupling value:

κ_λ ϵ [-1.7, 6.6]

Conclusion

This year we reached 2 milestones with $HH \rightarrow \bar{b}b\gamma\gamma$:

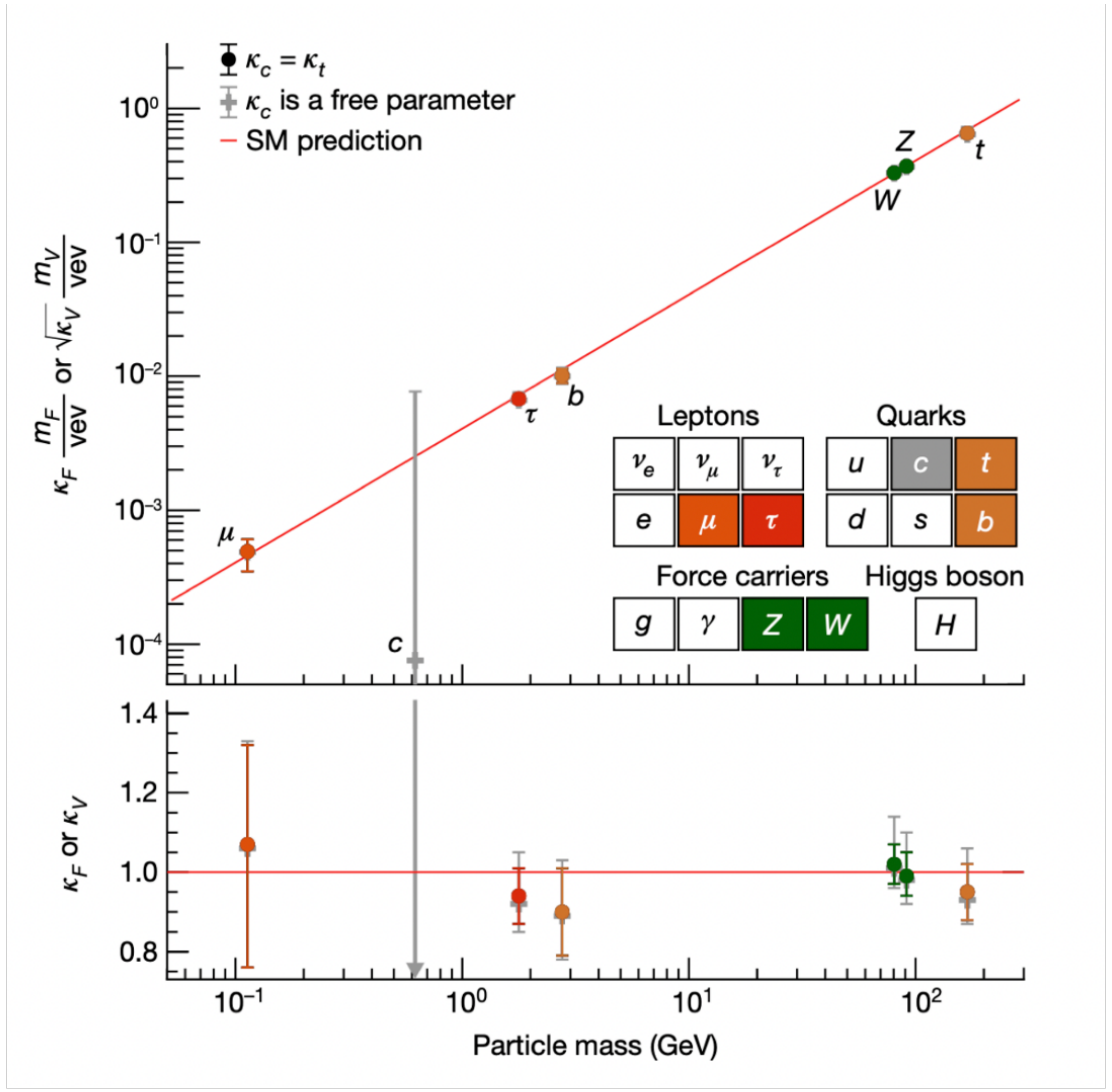
- First result with 308fb^{-1} of data
- First time reaching 1σ sensitivity for di-Higgs production

We are getting closer to seeing the first evidence and measuring the self-coupling (Run 3, HL-LHC)

Nikhef involvement growing

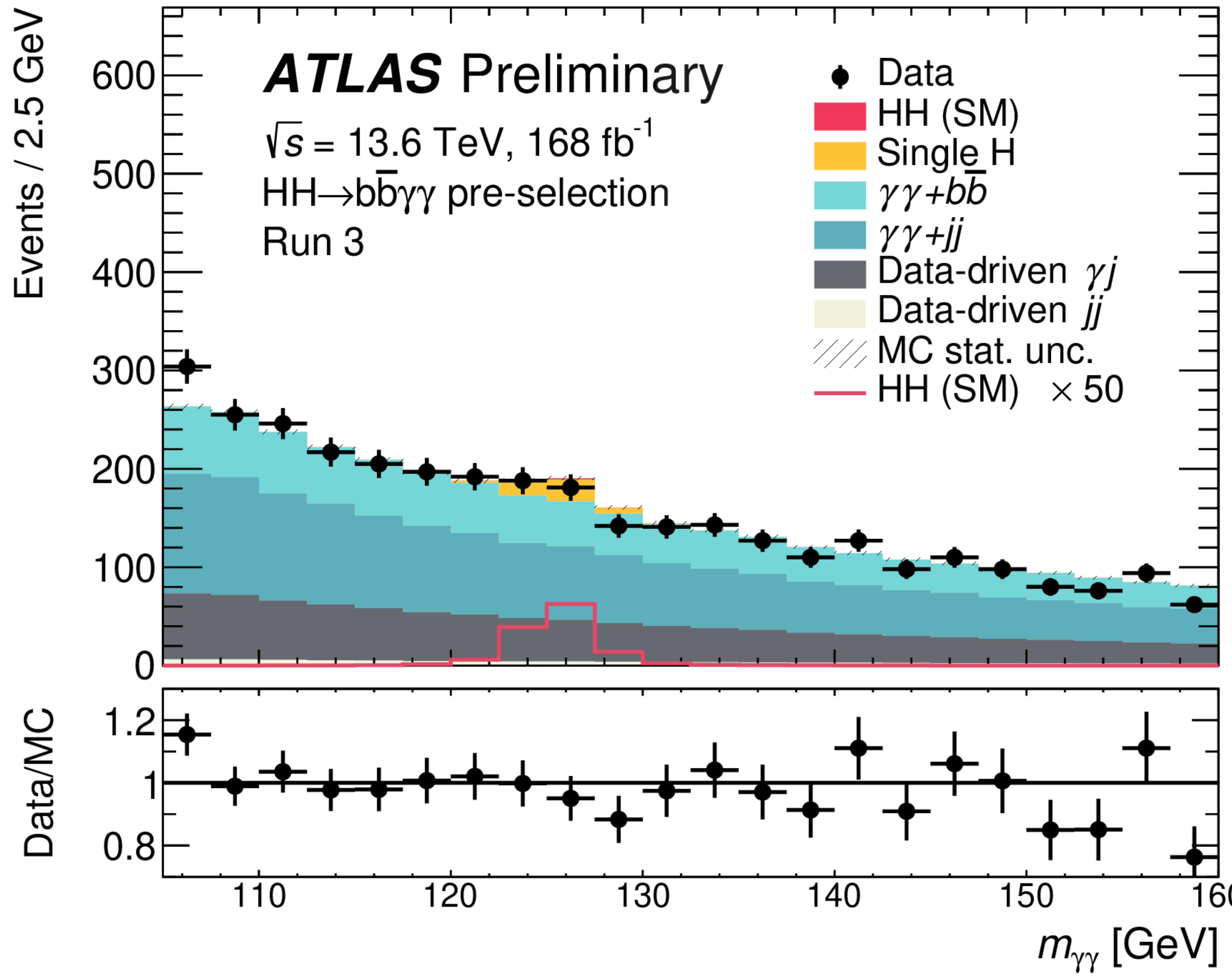
BACKUP

Backup



Nature 607, 52–59 (2022)

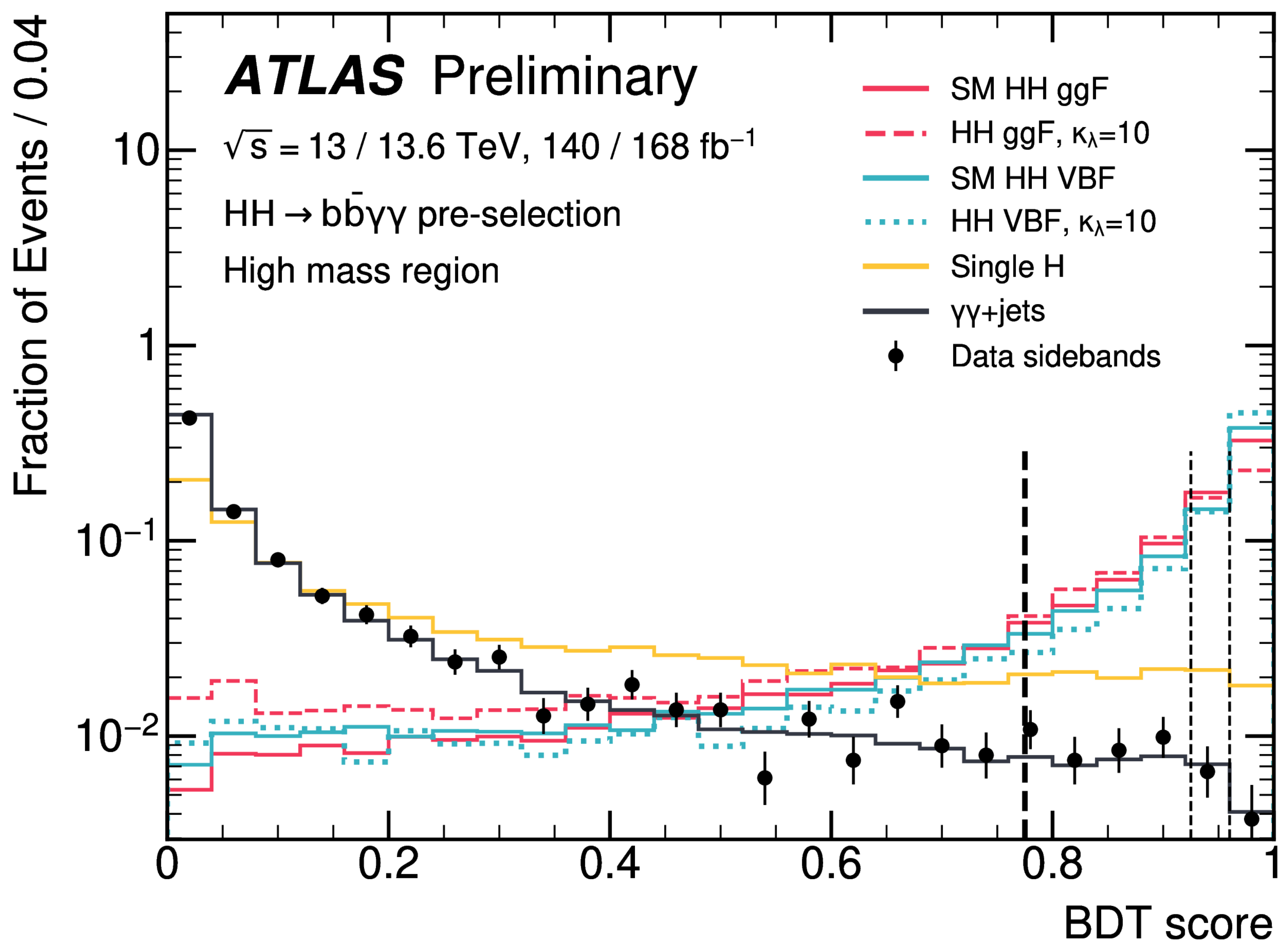
Backup

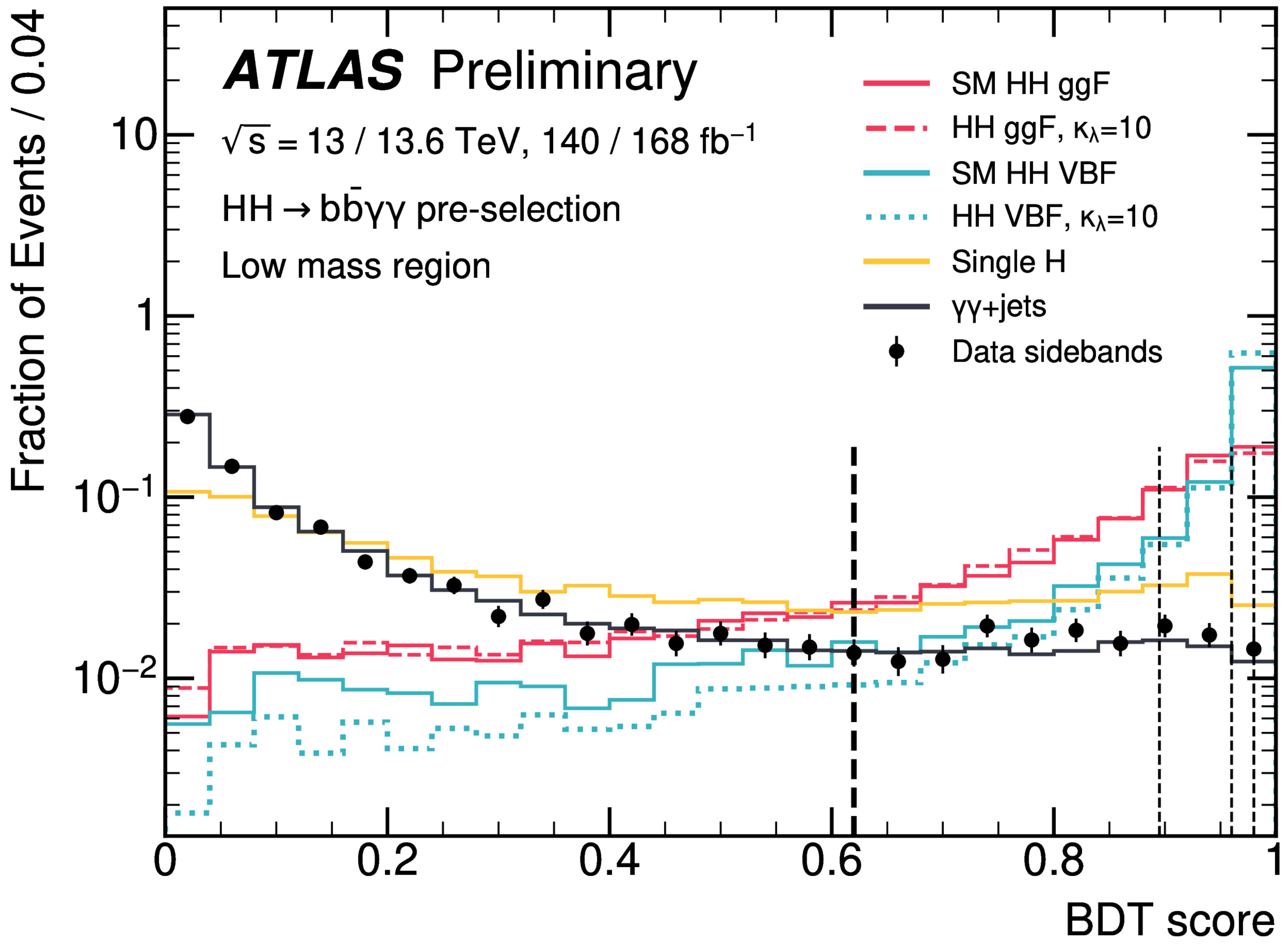


ATLAS Preliminary
$\sqrt{s}$ = 13.6 TeV, 168 fb^{-1}
HH→$b\bar{b}\gamma\gamma$ pre-selection
Run 3
Data
HH (SM)
Single H
$\gamma\gamma+b\bar{b}$
$\gamma\gamma+jj$
Data-driven γj
Data-driven jj
MC stat. unc.
HH (SM) × 50
Events / 2.5 GeV
Data/MC
$m_{\gamma\gamma}$ [GeV]

BDT

Variable	Definition
Photon candidates	
$p_{\mathrm{T}}/m_{\gamma\gamma}$	Transverse momentum of each photon divided by the di-photon invariant mass $m_{\gamma\gamma}$
η and ϕ	Pseudorapidity and azimuthal angle of each photon
$\Delta R(\gamma_1, \gamma_2)$	Angular distance between the two photons
***b*-jet candidates**	
b-tag status	Tightest fixed b-tag working point (60%, 70%, 77%, 85%) that each jet fulfills
p_{T}, η and ϕ	Transverse momentum, pseudorapidity and azimuthal angle of each jet
$p_{\mathrm{T}}^{b\bar{b}}$, $\eta_{b\bar{b}}$ and $\phi_{b\bar{b}}$	Transverse momentum, pseudorapidity and azimuthal angle of the two-b-jet system
$\Delta R(b_1, b_2)$	Angular distance between the two b-jets
$m_{b\bar{b}}$	Invariant mass of the two b-jets
Single topness	Variable used to identify $t \to Wb \to q\bar{q}'b$ decays. For the definition, see Ref. [30].
Other jets (only first two, if present, ranked by discrete *b*-tagging score)	
b-tag status	Tightest fixed b-tag working point that each jet fulfills
p_{T}, η and ϕ	Transverse momentum, pseudorapidity and azimuthal angle of each jet
VBF-jet candidates	
$\Delta\eta_{jj}$, m_{jj}	Pseudorapidity difference and invariant mass of the two jets
Event-level variables	
Transverse sphericity, planar flow, p_{T} balance	For the definitions, see respectively Refs. [30, 109, 110]
H_{T}	Scalar sum of the p_{T} of the jets in the event
$E_{\mathrm{T}}^{\mathrm{miss}}$ and ϕ^{miss}	Missing transverse momentum and its azimuthal angle
$m^*_{b\bar{b}\gamma\gamma}$	The four-body invariant mass of the two photons and two b-jets, $m^*_{b\bar{b}\gamma\gamma} = m_{b\bar{b}\gamma\gamma} - (m_{b\bar{b}} - 125\text{ GeV}) - (m_{\gamma\gamma} - 125\text{ GeV})$





Categorisation

Category	Selection criteria
High Mass 1	$m^*_{b\bar{b}\gamma\gamma} \geq 350$ GeV, BDT score $\in [0.775, 0.925]$
High Mass 2	$m^*_{b\bar{b}\gamma\gamma} \geq 350$ GeV, BDT score $\in [0.925, 0.960]$
High Mass 3	$m^*_{b\bar{b}\gamma\gamma} \geq 350$ GeV, BDT score $\in [0.960, 1.000]$
Low Mass 1	$m^*_{b\bar{b}\gamma\gamma} < 350$ GeV, BDT score $\in [0.620, 0.895]$
Low Mass 2	$m^*_{b\bar{b}\gamma\gamma} < 350$ GeV, BDT score $\in [0.895, 0.960]$
Low Mass 3	$m^*_{b\bar{b}\gamma\gamma} < 350$ GeV, BDT score $\in [0.960, 0.980]$
Low Mass 4	$m^*_{b\bar{b}\gamma\gamma} < 350$ GeV, BDT score $\in [0.980, 1.000]$

Impact of systematics

Systematic uncertainty source	Relative impact [%] Expected	Relative impact [%] Observed
Experimental		
Photon energy scale	< 0.1	3.6
Photon energy resolution	< 0.1	0.4
Photon efficiency	0.2	0.3
Jet	0.3	< 0.1
Theoretical		
QCD Scale + m_{top}, PDF+α_S	5.2	6.1
$\mathcal{B}(H \to \gamma\gamma, b\bar{b})$	0.2	0.3
Parton showering model	1.0	0.3
Heavy-flavour content	3.3	1.0
Background model (spurious signal)	0.2	< 0.1

Detailed results

	Run 2		Run 3		Combined	
	observed	expected	observed	expected	observed	expected
μ_{HH}	$0.6^{+1.8}_{-1.1}$	$1^{+2.1}_{-1.3}$	$1.4^{+2.2}_{-1.7}$	$1^{+1.9}_{-1.3}$	$0.9^{+1.4}_{-1.1}$	$1^{+1.3}_{-1.0}$
κ_λ (68% CI)	$[-0.2, 4.3]$	$[-1.2, 6.3]$	$[-1.5, 7.1]$	$[-1.0, 6.0]$	$[-0.4, 5.1]$	$[-0.6, 5.4]$
κ_λ (95% CI)	$[-1.8, 6.4]$	$[-2.9, 8.0]$	$[-3.3, 8.5]$	$[-2.6, 7.7]$	$[-1.7, 6.6]$	$[-1.8, 6.9]$
κ_{2V} (68% CI)	$[-0.2, 2.4]$	$[-0.2, 2.3]$	$[-0.2, 2.3]$	$[-0.1, 2.2]$	$[0.0, 2.1]$	$[0.1, 2.1]$
κ_{2V} (95% CI)	$[-0.9, 3.1]$	$[-0.9, 3.0]$	$[-0.8, 3.0]$	$[-0.7, 2.9]$	$[-0.5, 2.6]$	$[-0.4, 2.6]$