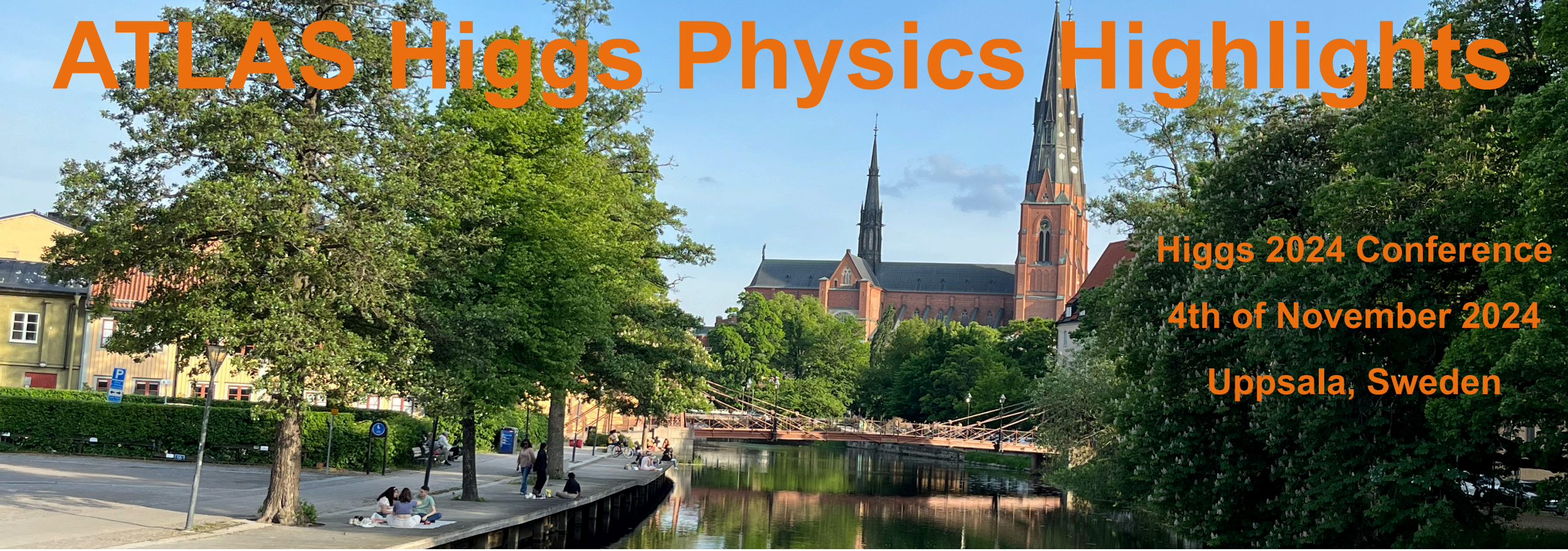
ATLAS Higgs Physics Highlights



Higgs 2024 Conference

4th of November 2024

Uppsala, Sweden

Serhat Ördek
on behalf of:

ATLAS EXPERIMENT

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

HELMHOLTZ

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

Recent Higgs boson studies in ATLAS

A biased selection

Brand-new results marked in Comic Sans

- Single SM Higgs analyses:
  - Joint study of VH production in $H \to b\bar{b}$ and $H \to c\bar{c}$ decays
  - Differential cross-section measurement in $H \to \tau\tau$ decays
  - Off-shell Higgs boson production measurement in $H^* \to ZZ \to 4\ell$
- Search for light charged Higgs bosons to $H^{\pm} \to cs$
- Searches for production of multiple Higgs bosons:
  - Combination of searches for non-resonant HH production
  - Search for HHH production in $6b$ final states

The Catcher and the Why

Apologies to J. D. Salinger

Measurements of single Higgs boson production

- Fundamental properties: mass, width, spin/CP
- Coupling strengths to other particles
- Production xsec as a function of event kinematics, N_{jets}, … (STXS)

Searches for additional Higgs bosons

- Motivated by solutions that models have for SM's problems
- Modify baryogenesis, provide DM candidate, solve strong CP problem, …

Searches for multi-Higgs production

- Coupling strength to itself
- Higher-order coupling: $HHVV$

The Catcher and the Why

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- Modify baryogenesis, provide DM candidate, solve strong CP problem, …

$H^{\pm} \to cs$

$HHH \to 6b$

$H^* \to ZZ$

$H \to bb/cc$
$H \to \tau\tau$

$H \to bb$
$H \to \tau\tau$

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HH comb.
$HHH \to 6b.$

HH comb.

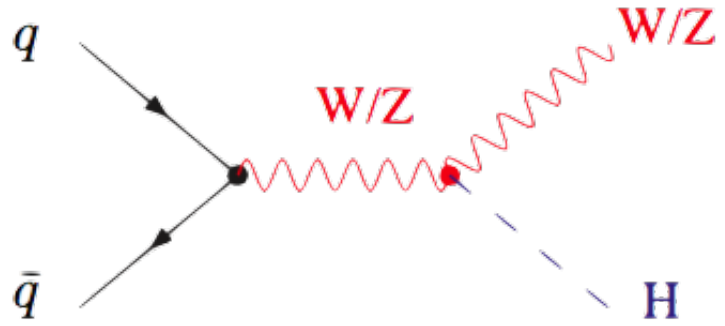
Searches for multi-Higgs production

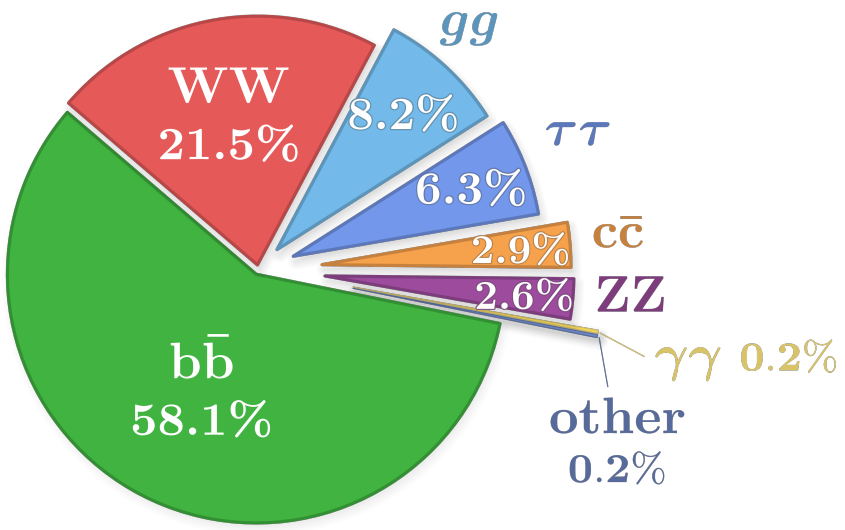
- Coupling strength to itself
- Higher-order coupling: $HHVV$

Highlight 1: $VH, H \to b\bar{b}/c\bar{c}$

General overview

- VH has third highest H production xsec at LHC
- Can easily tag VH events with $V \to$ leptons decays
  $\Rightarrow$ Best production mode to study $H \to q\bar{q}$



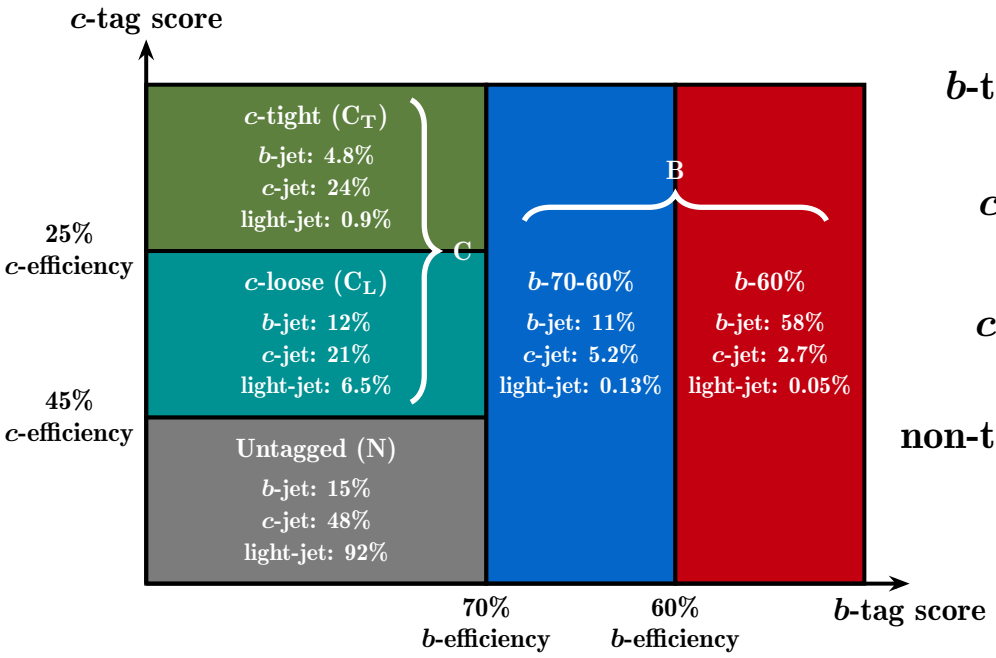


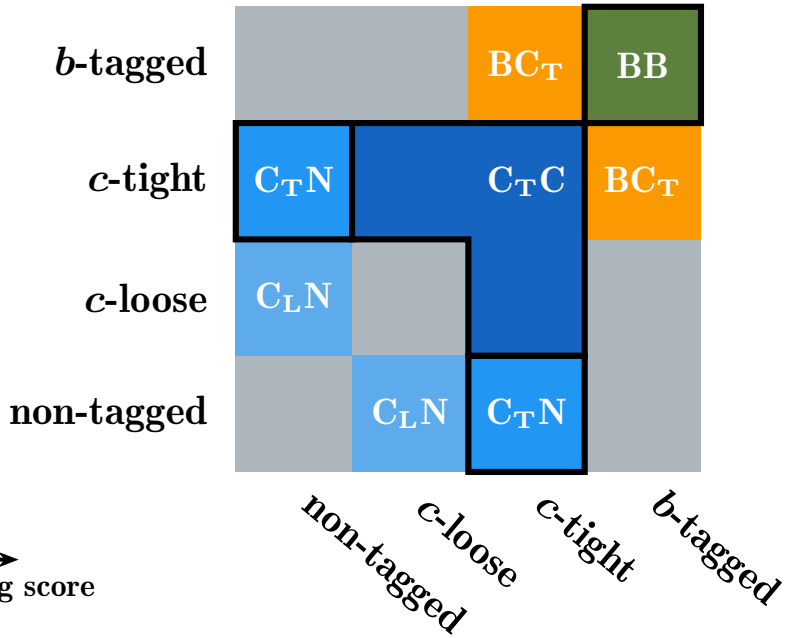
- Decay to $b\bar{b}$ is important as it has highest BR
- Strong effect on Higgs decay width, need precise knowledge for general interpretations
- $H \to c\bar{c}$ decay, like all other 2nd gen. fermions, not yet observed:
  - Much lower branching ratio than $b\bar{b}$
  - Very difficult experimentally to identify c-initiated jets
  - Large $Z + c$ background

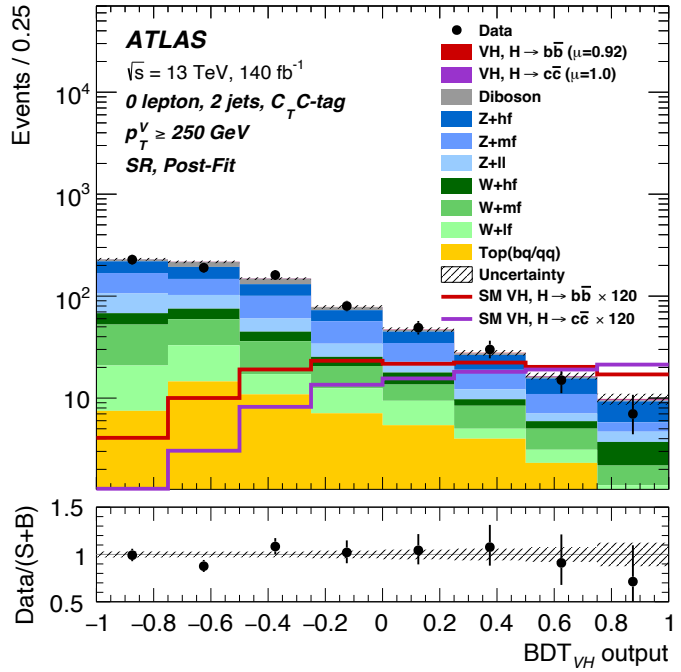
Highlight 1: $VH, H \to b\bar{b}/c\bar{c}$

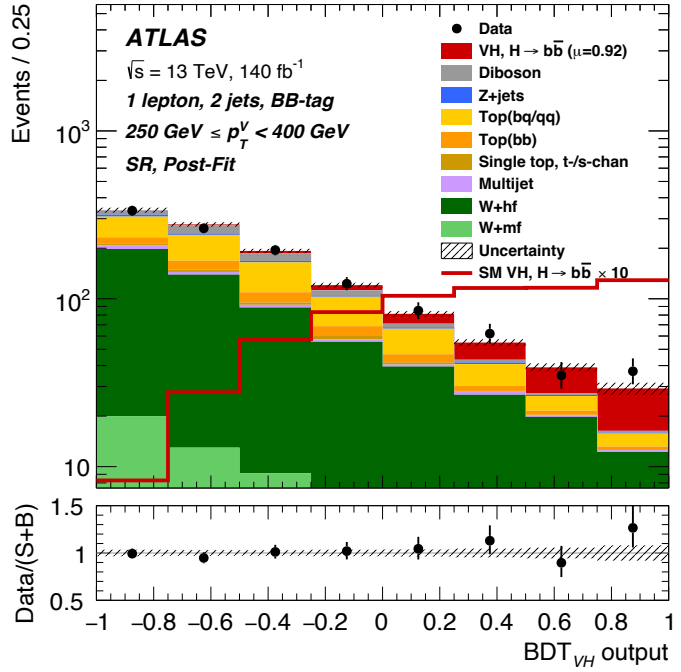
Analysis setup

- Re-analysis of 140 fb^{-1} Run 2 dataset: 2410.19611
- Split events by number of charged leptons produced by V decay: 0, 1 or 2
- 2D jet flavour tagging setup to keep b- and c-jets apart
- To better control fake b/c-jet contributions, include mixed-tag regions





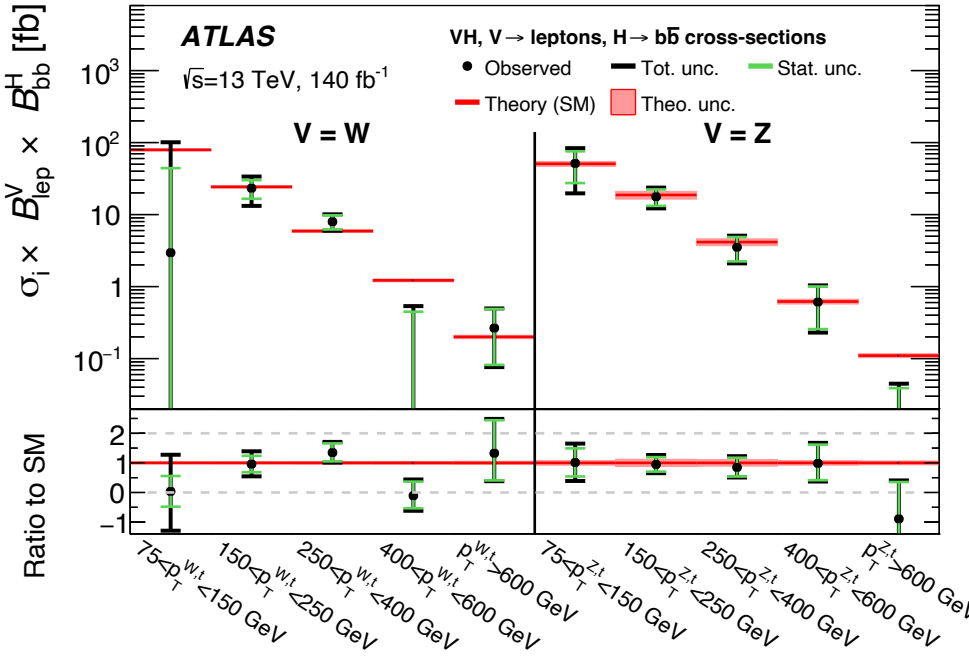


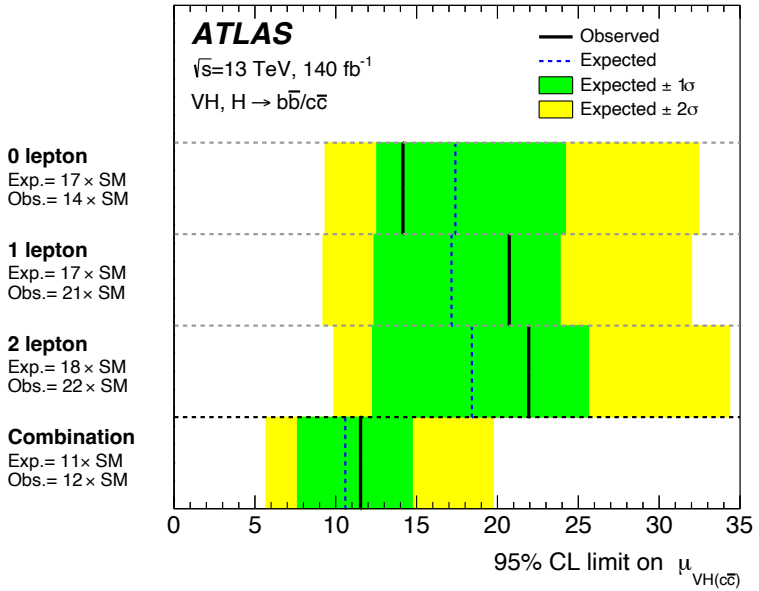


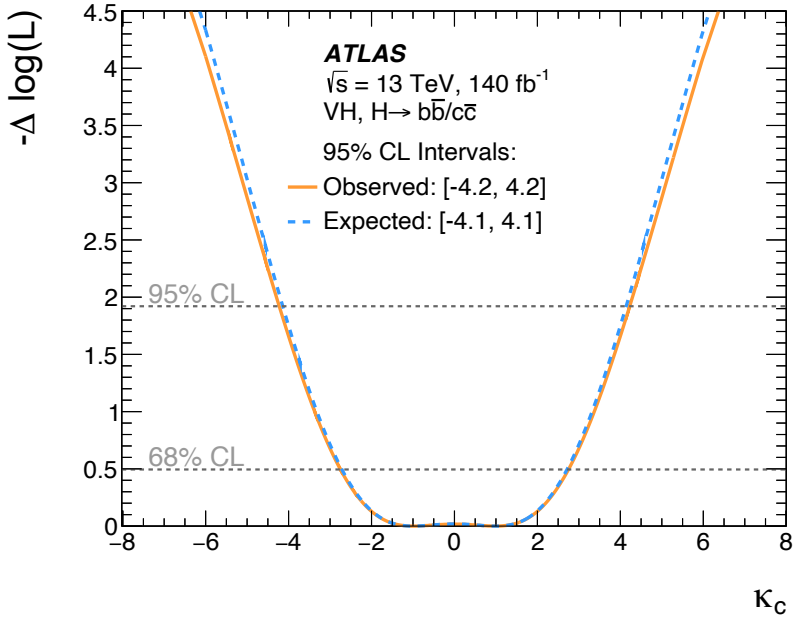
Highlight 1: $VH, H \to b\bar{b}/c\bar{c}$

A selection of results

- Big improvements over $H \to b\bar{b}$ results in previous analysis
- 23% (10%) better precision on total WH (ZH) signal strength
- Additional STXS bins at lowest/highest p_{T}^{V} and split by N_{jets}
- First 5σ observation of $WH, H \to b\bar{b}$ process



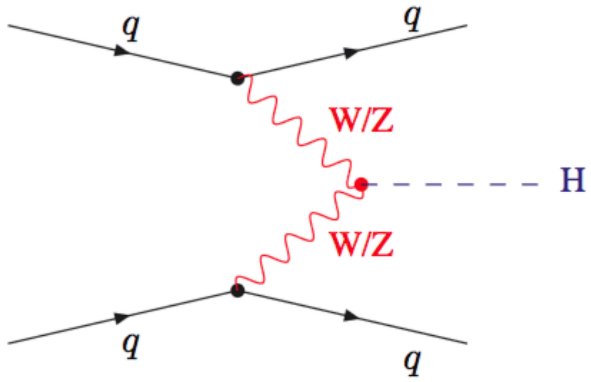




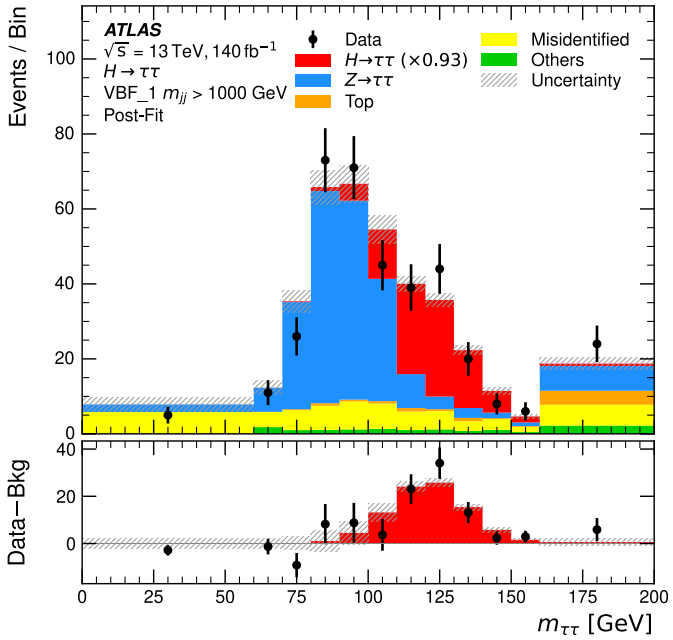
- Limit on $H \to c\bar{c}$ signal strength improved by a factor of ≈3 wrt first full Run 2 result
- Similar improvement on κ_c constraint
- See M. Missio's talk on Wednesday

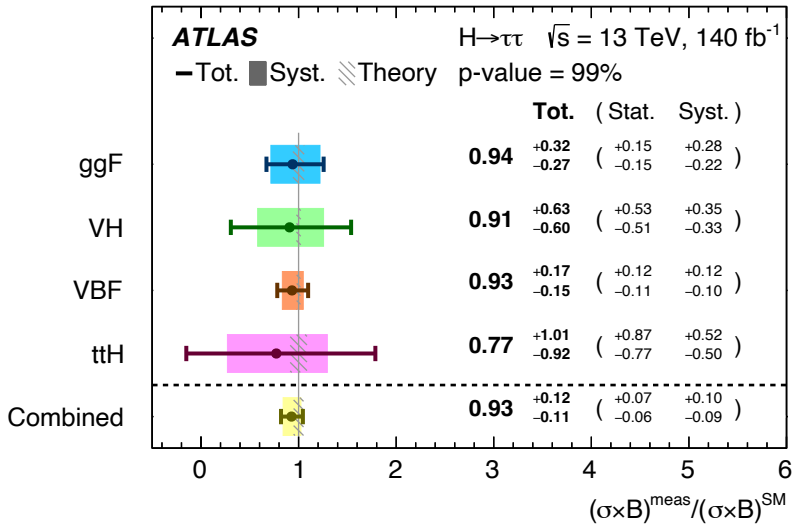
Highlight 2: $H \to \tau\tau$ measurement

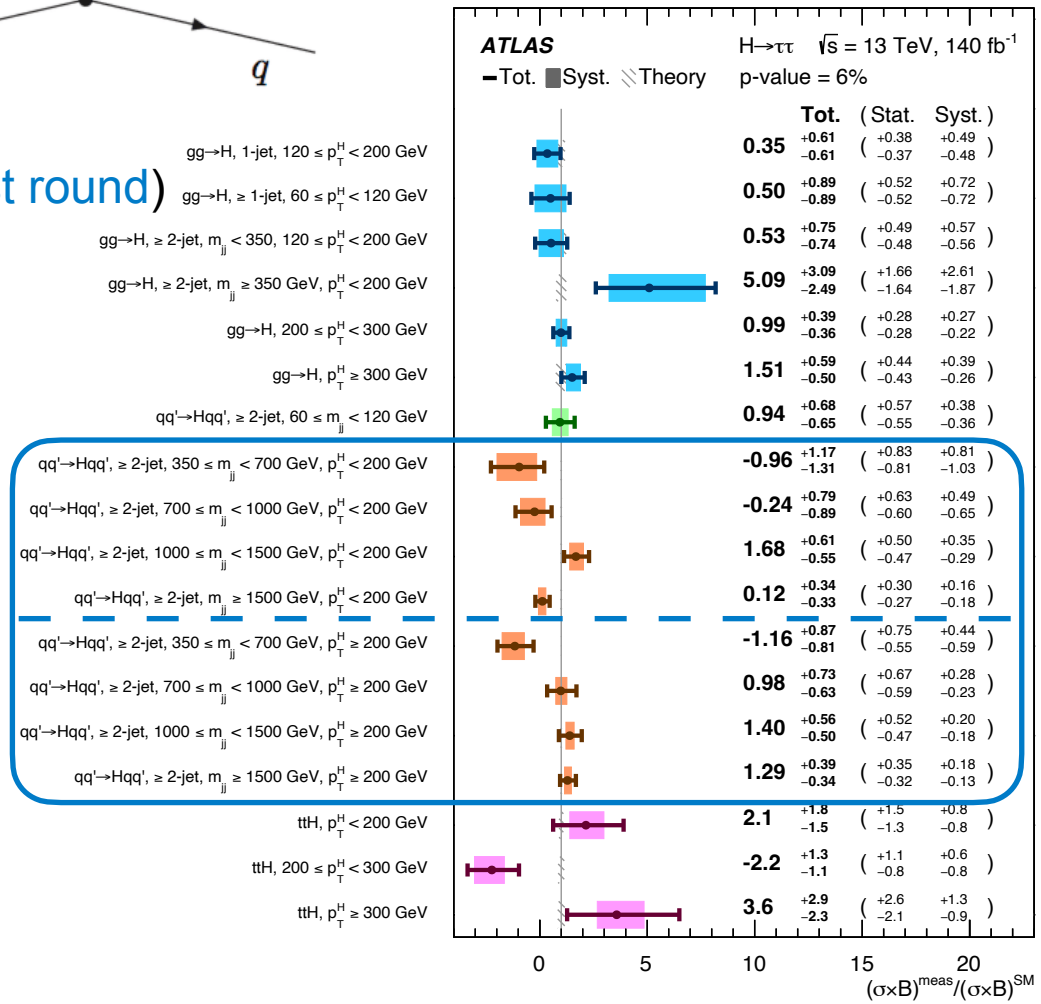
General overview



- Re-analysis of Run 2 data: 2407.16320
- $H \to \tau\tau$ decay has largest BR to leptons
- Strongest decay mode for measuring VBF xsec (+ $\approx 15\,\%$ wrt last round)
- First STXS VBF measurement for $p_{\mathrm{T}}^{H} > 200$ GeV



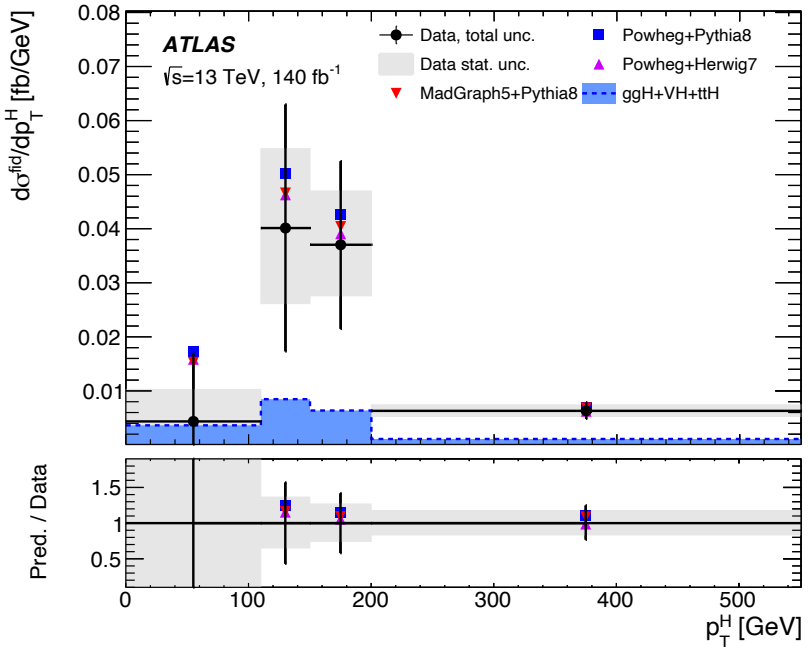


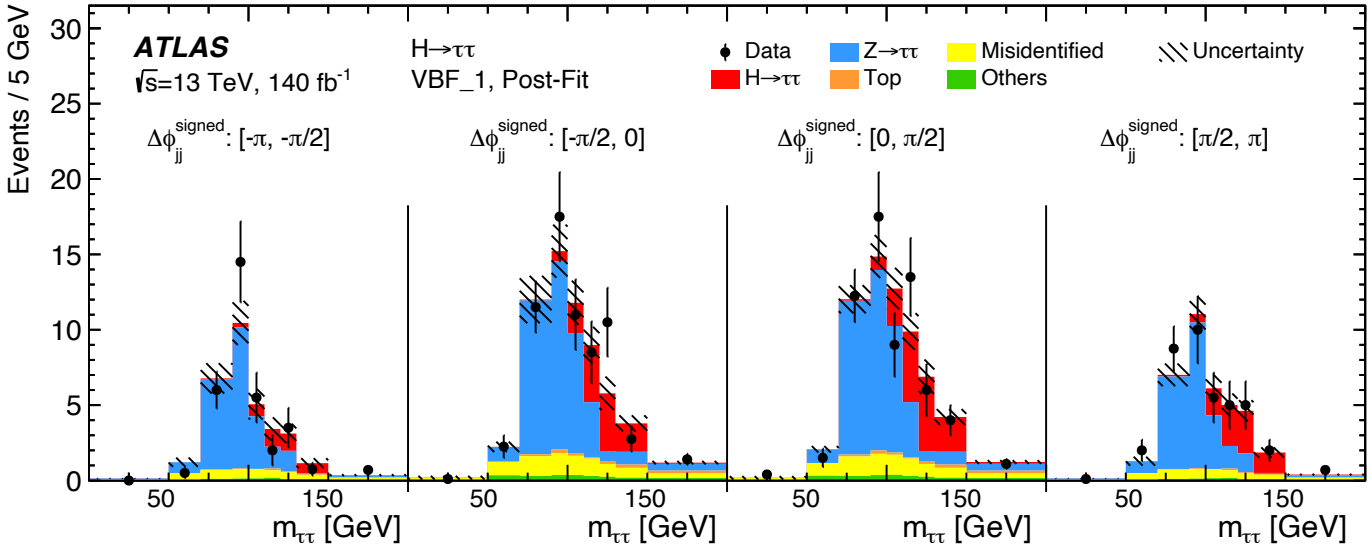


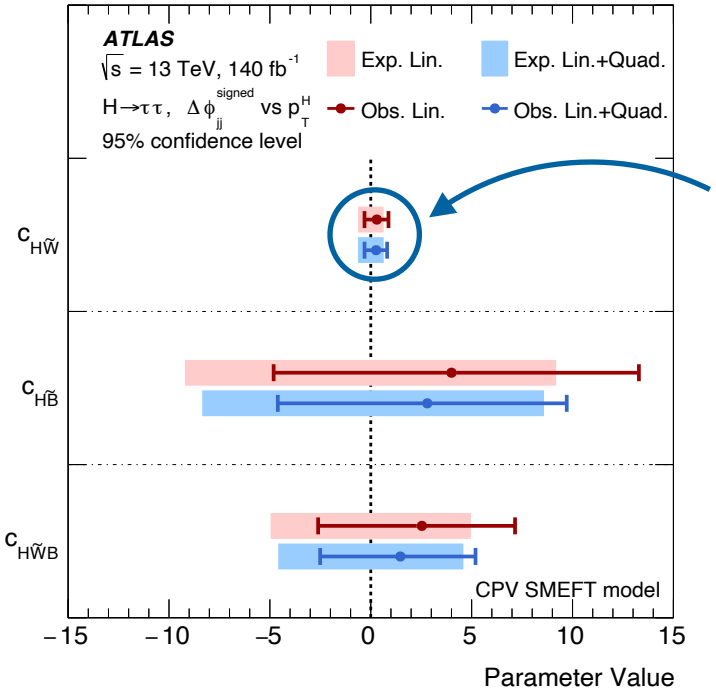
Highlight 2: $H \to \tau\tau$ measurement

Differential cross-section measurement

- Also measured differential VBF cross-sections
- Split events into four bins of e.g. p_{T}^{H} or $\Delta\phi_{jj}^{\mathrm{signed}}$, fit $m_{\tau\tau}$
- Very good agreement with different generators
- SMEFT interpretation based on differential xsec measurement
- See E. Valiente's talk on Wednesday





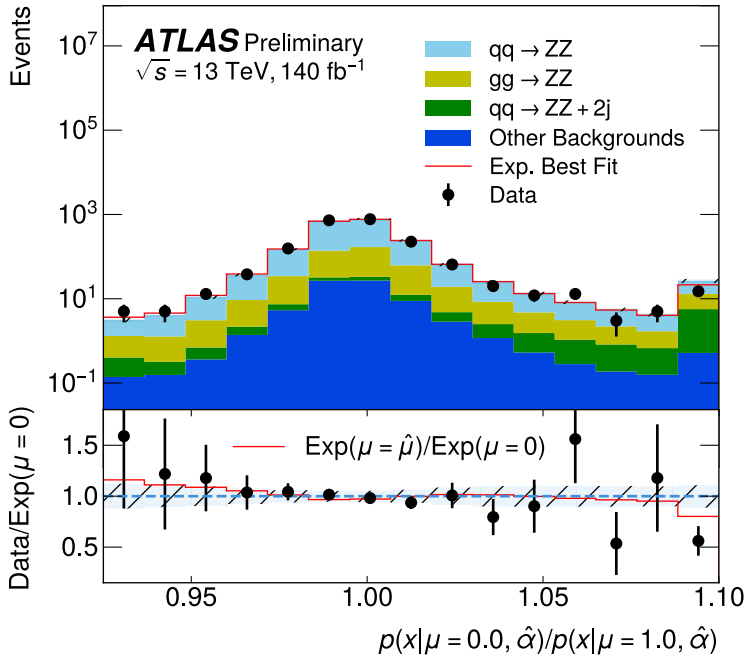


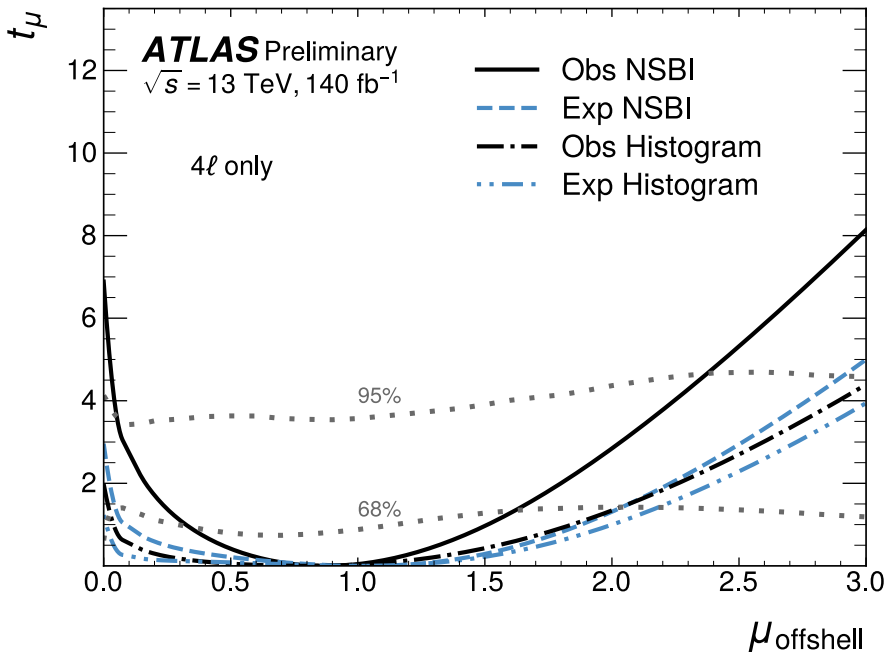
Most stringent constraint to date on CP-odd dim-6 operator $H^{\dagger}H\tilde{W}^{n}_{\mu\nu}W^{n\mu\nu}$

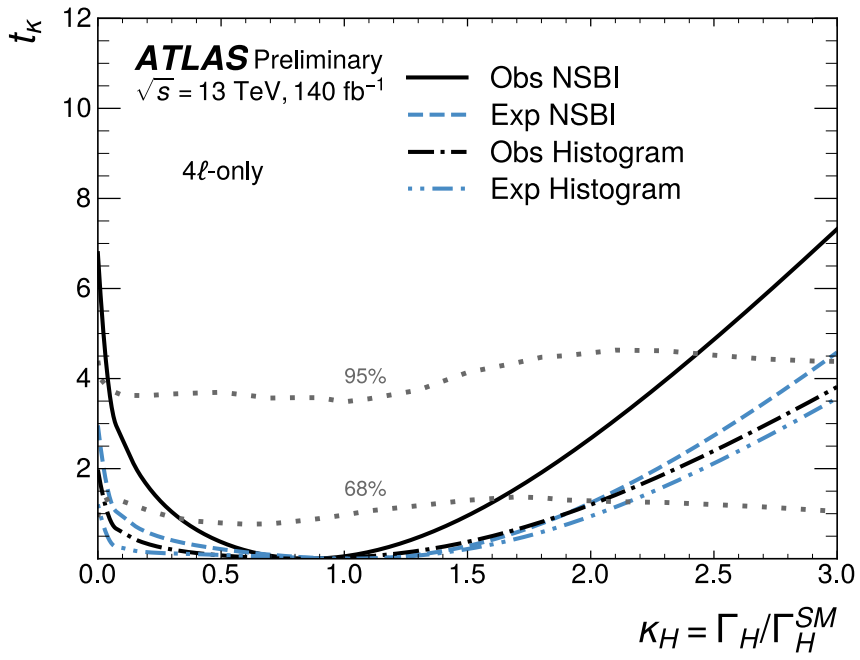
Highlight 3: Off-shell $H^* \to ZZ \to 4\ell$ measurement

New measurement of the Higgs boson decay width

- Re-analysis of off-shell Higgs boson production in 4ℓ final states: ATLAS-CONF-2024-016
- Using Neural Simulation-Based Inference method to maximise statistical power of Run 2 dataset (+ $\approx 20\,\%$)
- Indirect measurement of Higgs boson decay width, assuming equal modifications to on-/off-shell couplings
- See J. Sandesara's talk at the end of the session

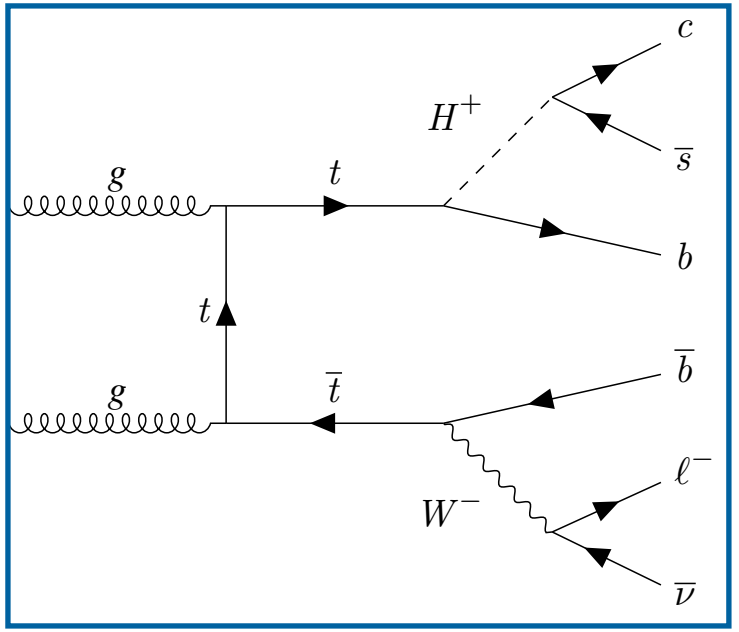




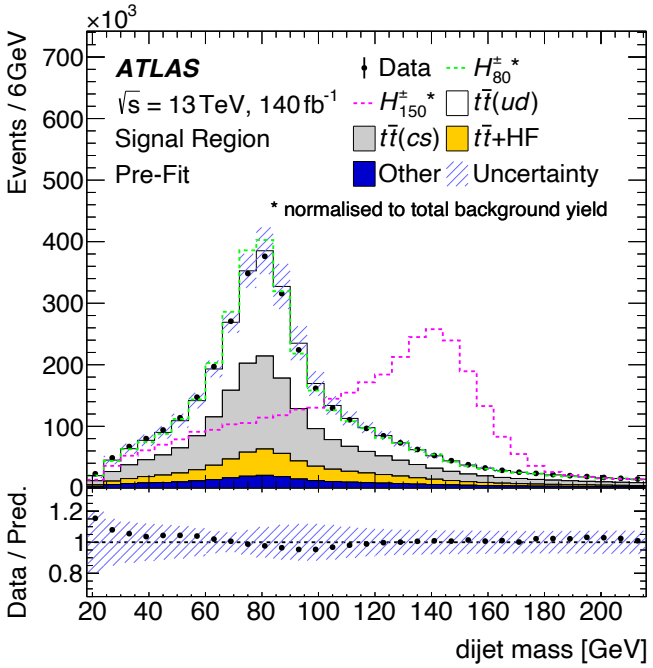


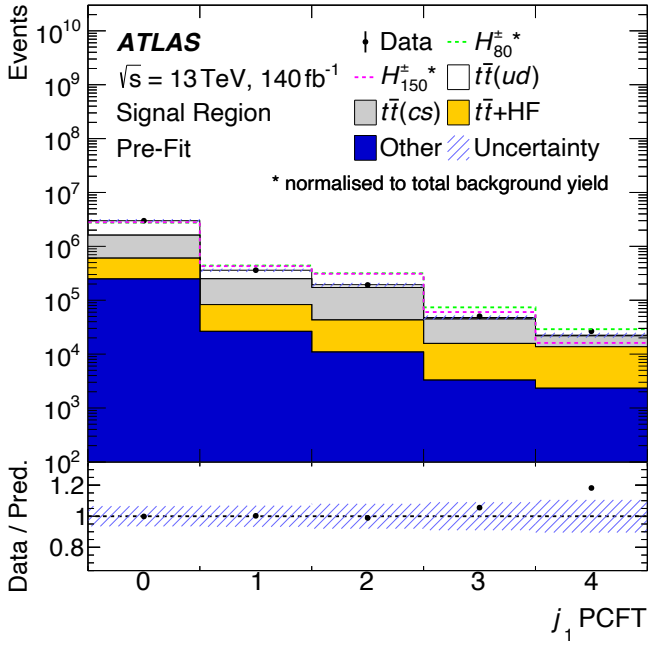
Highlight 4: Search for low-mass $H^{\pm} \to cs$

General overview



- $H^{\pm}$ part of many models which solve common problems of SM
- In Type-I 2HDMs, BR to $\tau\nu$ and cs highest
- In case of $m_{H^{\pm}} < m_t$, most common production mode is through $t\bar{t}$ pair





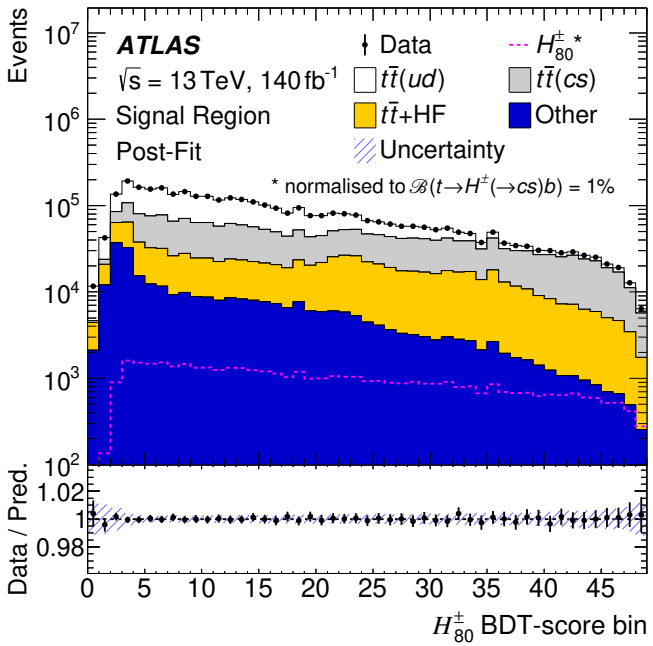
- Search for this signature: 2407.10096
- Similar to SM $t\bar{t}$, especially for $m_{H^{\pm}} \approx m_W$
- BDTs to distinguish these, but less separation power for $m_{H^{\pm}} \approx m_W$
- In that case, flavour-tagging info most useful

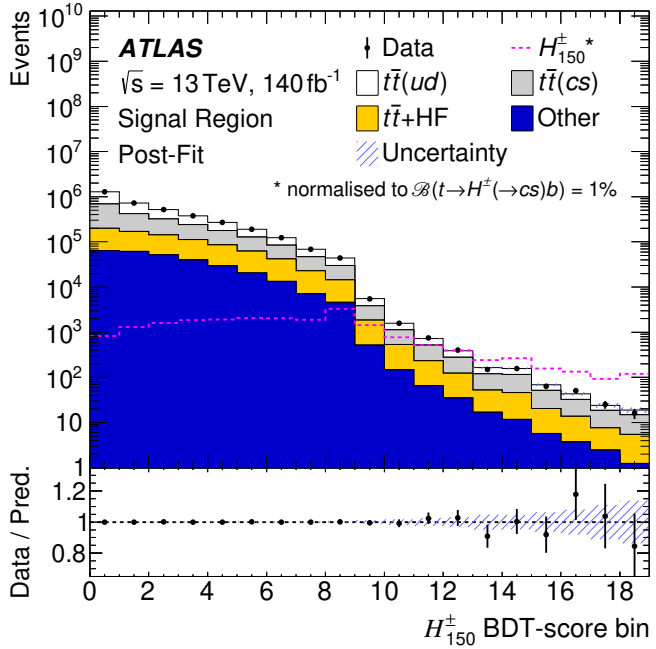
Highlight 4: Search for low-mass $H^{\pm} \to cs$

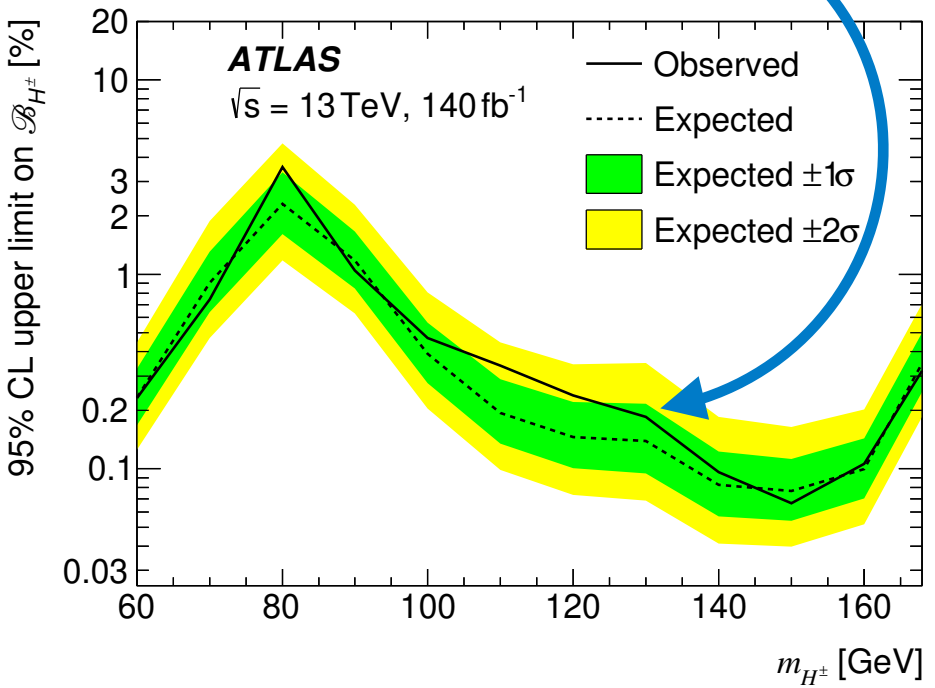
Branching ratio limits

- As expected, more steeply falling BDT scores for high-mass signal
- No hint of signal found, setting limits on $t \to H^{\pm}b$ branching fraction
- Weakest limit at $m_{H^{\pm}} = 80$ GeV, strongest at $m_{H^{\pm}} = 150$ GeV
- See O. Ducu's talk tomorrow

Mild excess found here in $H^{\pm} \to cb$



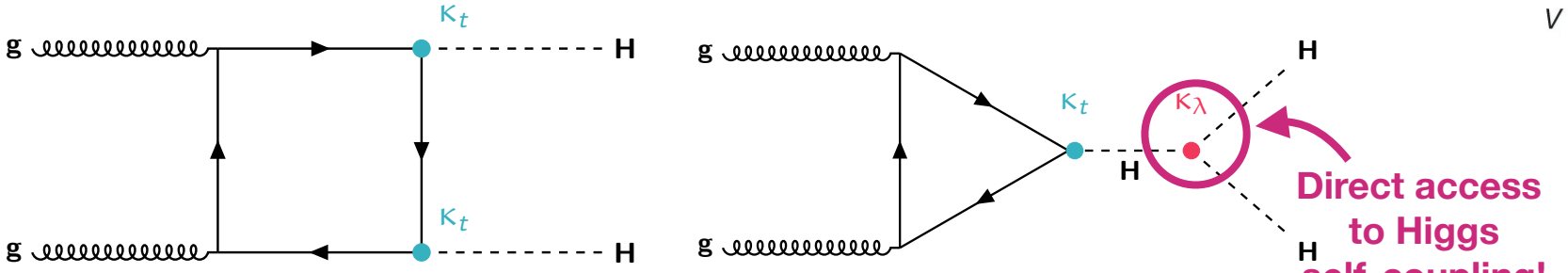


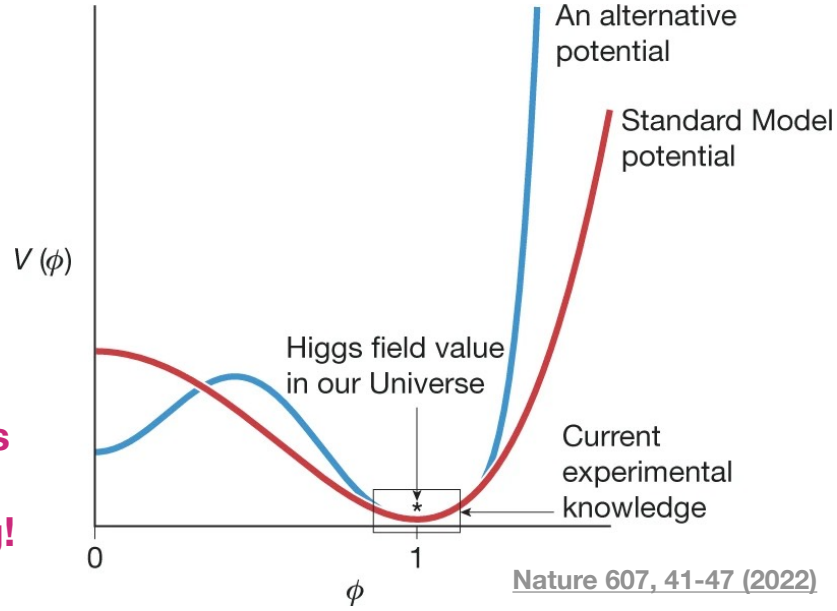


Highlight 5: Combination of searches for non-resonant HH

Context for the searches

- Main HH production mode at LHC is gluon fusion
- Destructive interference, xsec ≈ 1000 times smaller than for single H





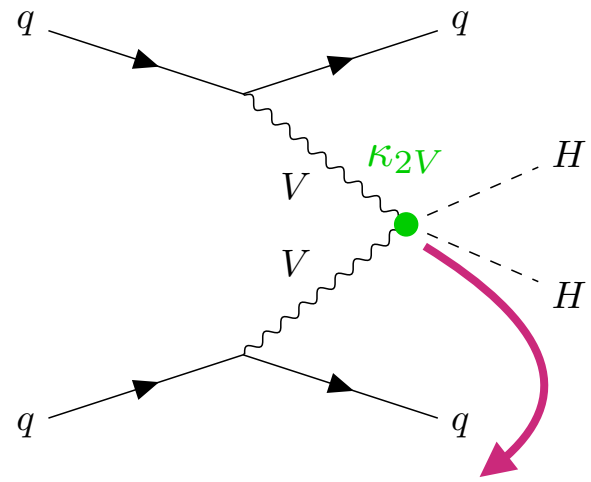
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

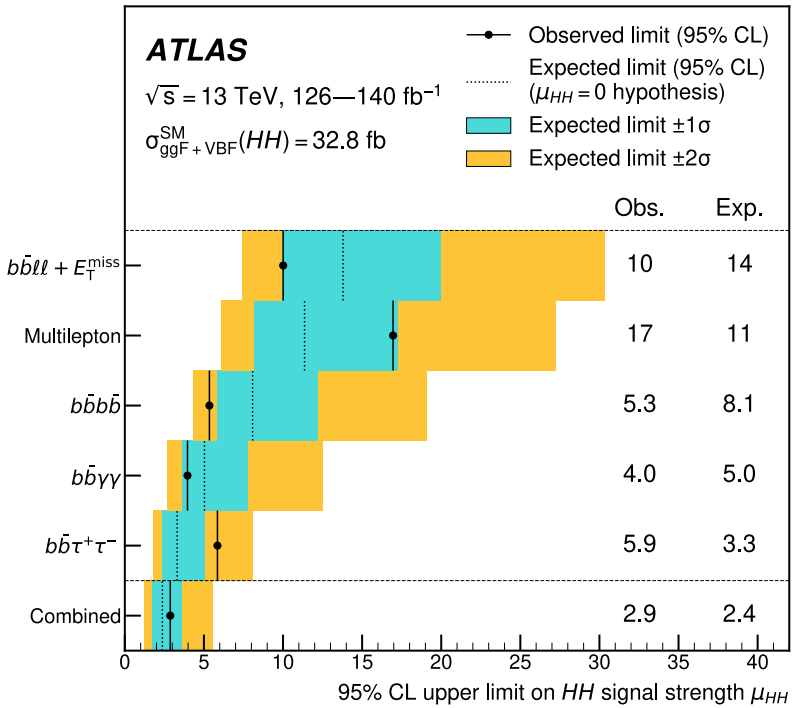
- HH production not yet observed experimentally
- 2 H decays ⇒ events distributed over many different final states
- New combination of searches from ATLAS: PRL 133 (2024) 101801
- More/updated input analyses and interpretations wrt last combination

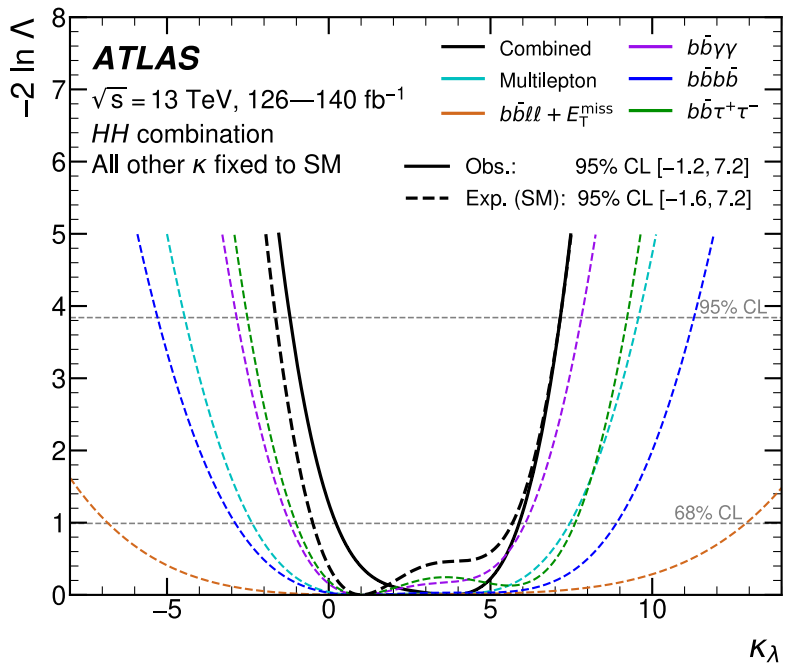
Highlight 5: Combination of searches for non-resonant HH

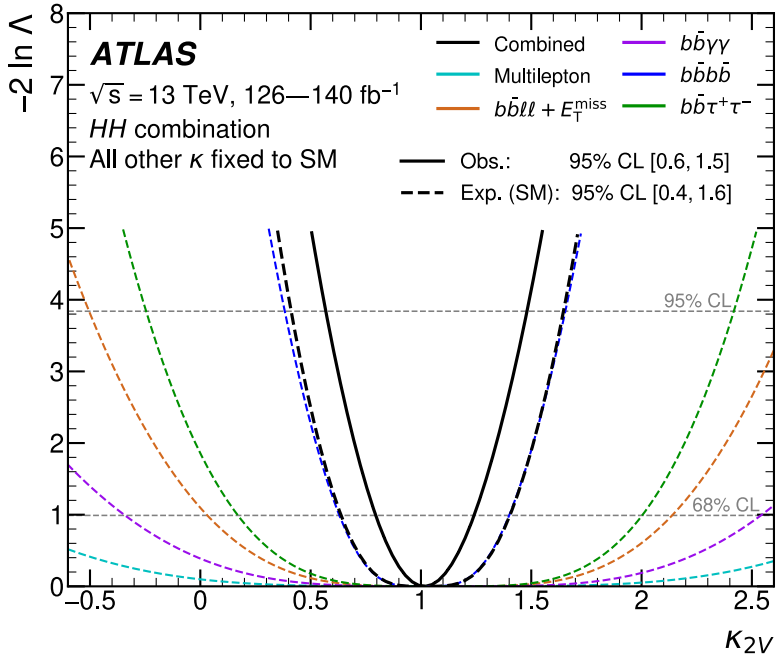
Combined results

- Expected upper limit on μ_{HH} improved by 17%
- Also placed constraints on κ_λ and $HHVV$ coupling modifier κ_{2V}
- Different strongest channel for each of these three results
- See more in W. Balunas' talk tomorrow



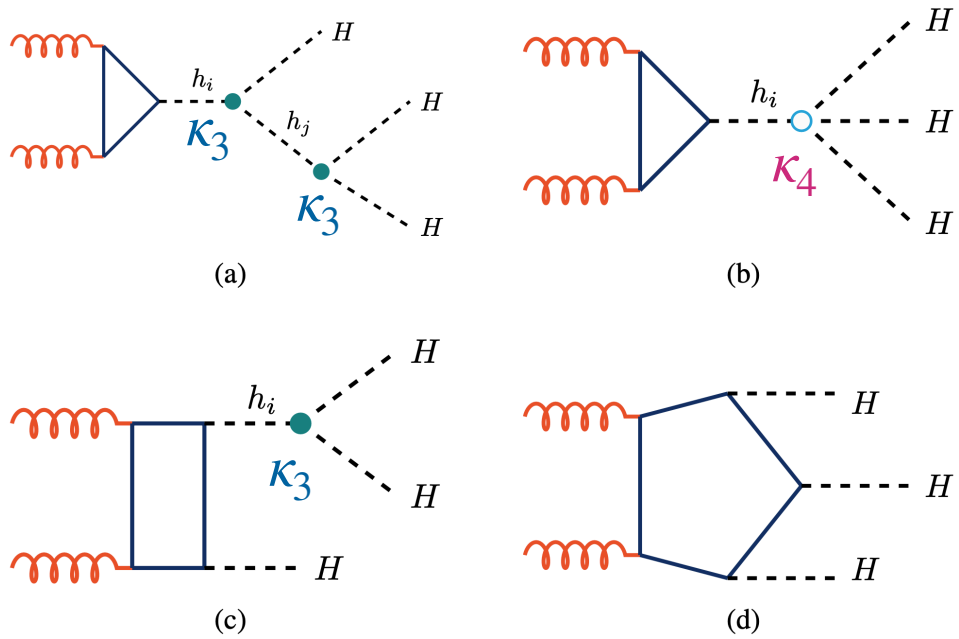




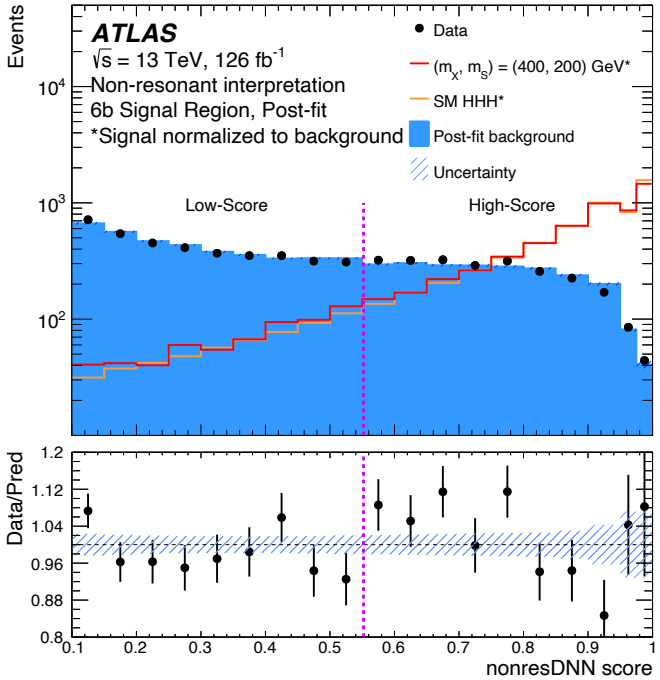


Highlight 6: Search for $HHH \to 6b$

Triple Higgs boson production



- HHH production is sensitive to $\kappa_3 (= \kappa_\lambda)$ and, uniquely, to κ_4
- But: $\frac{\sigma_{HH}^{\mathrm{SM}}}{\sigma_{HHH}^{\mathrm{SM}}} \approx 400$, and HH is not yet observed either
- Extremely small signal, distributed over many final states

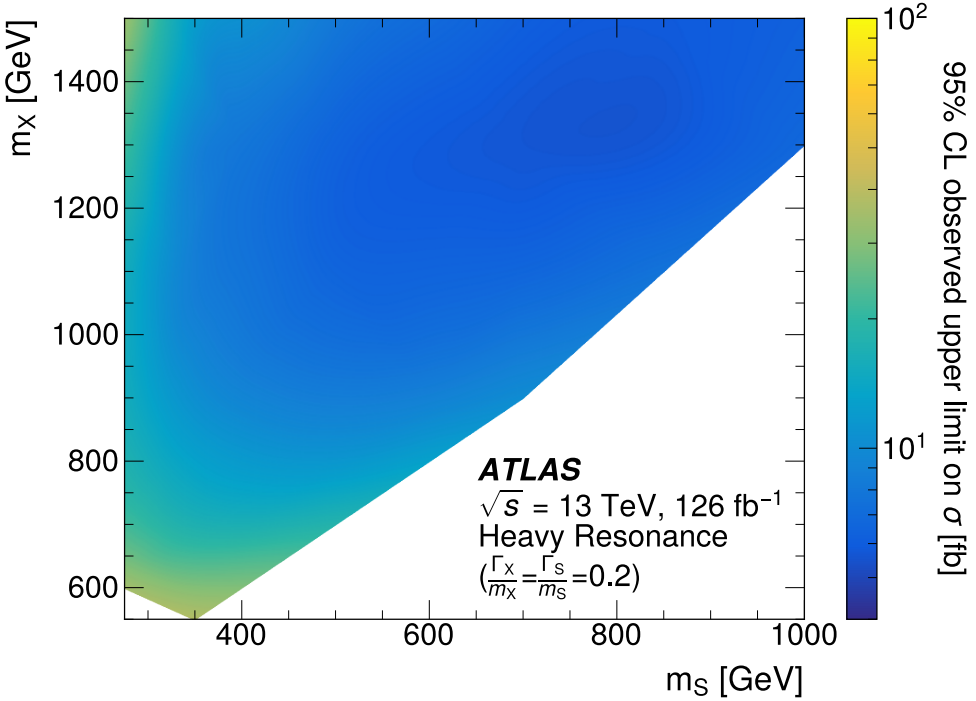


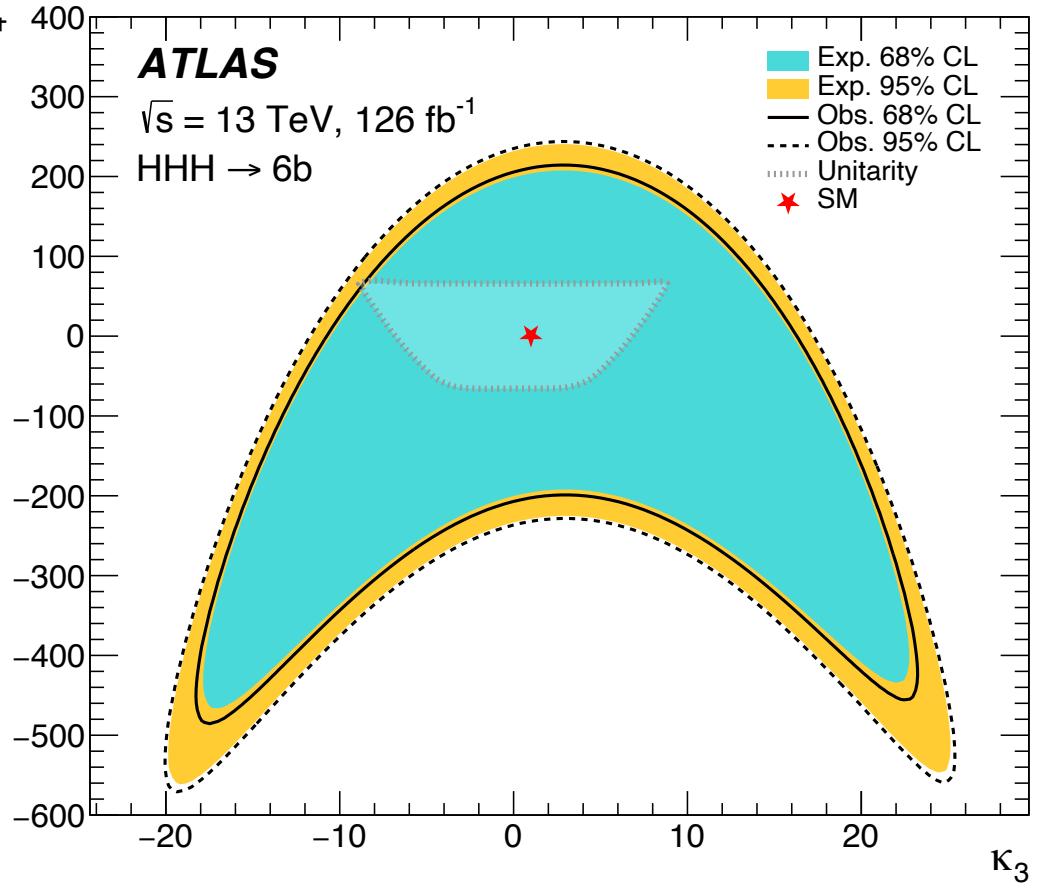
- But BSM physics can still produce a signal within reach of LHC (e.g. TRSM)
- First search for HHH at LHC, using $6b$ final state: HIGP-2024-32
- Searching for events with 6 b-tagged jets, 3 pairs with $m_{jj} \approx m_H$
- Considering not only SM-like HHH production but also resonances
- Different NNs trained to identify HHH events depending on signal hypothesis

Highlight 6: Search for $HHH \rightarrow 6b$

Results

- 95% CL upper limit on $\sigma_{HHH}/\sigma_{HHH}^{\mathrm{SM}}$ is ≈ 750
- First direct limits set on κ_4

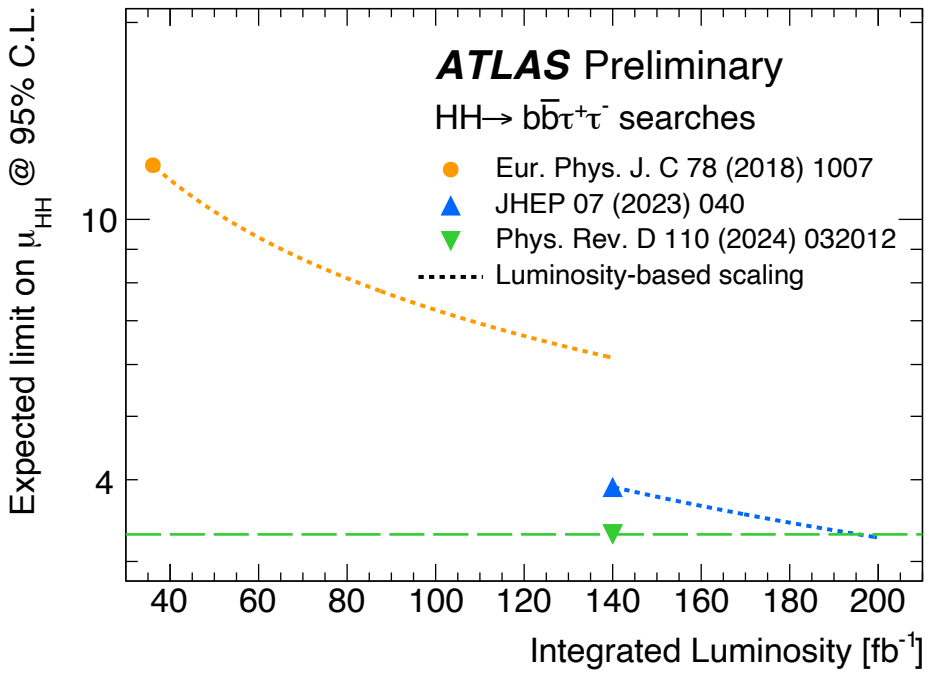




- Considered TRSM benchmark model for $X \rightarrow SH \rightarrow HHH$
- No excess over bkg found, set limits on large range of masses
- See M. Chen's talk tomorrow

Conclusion

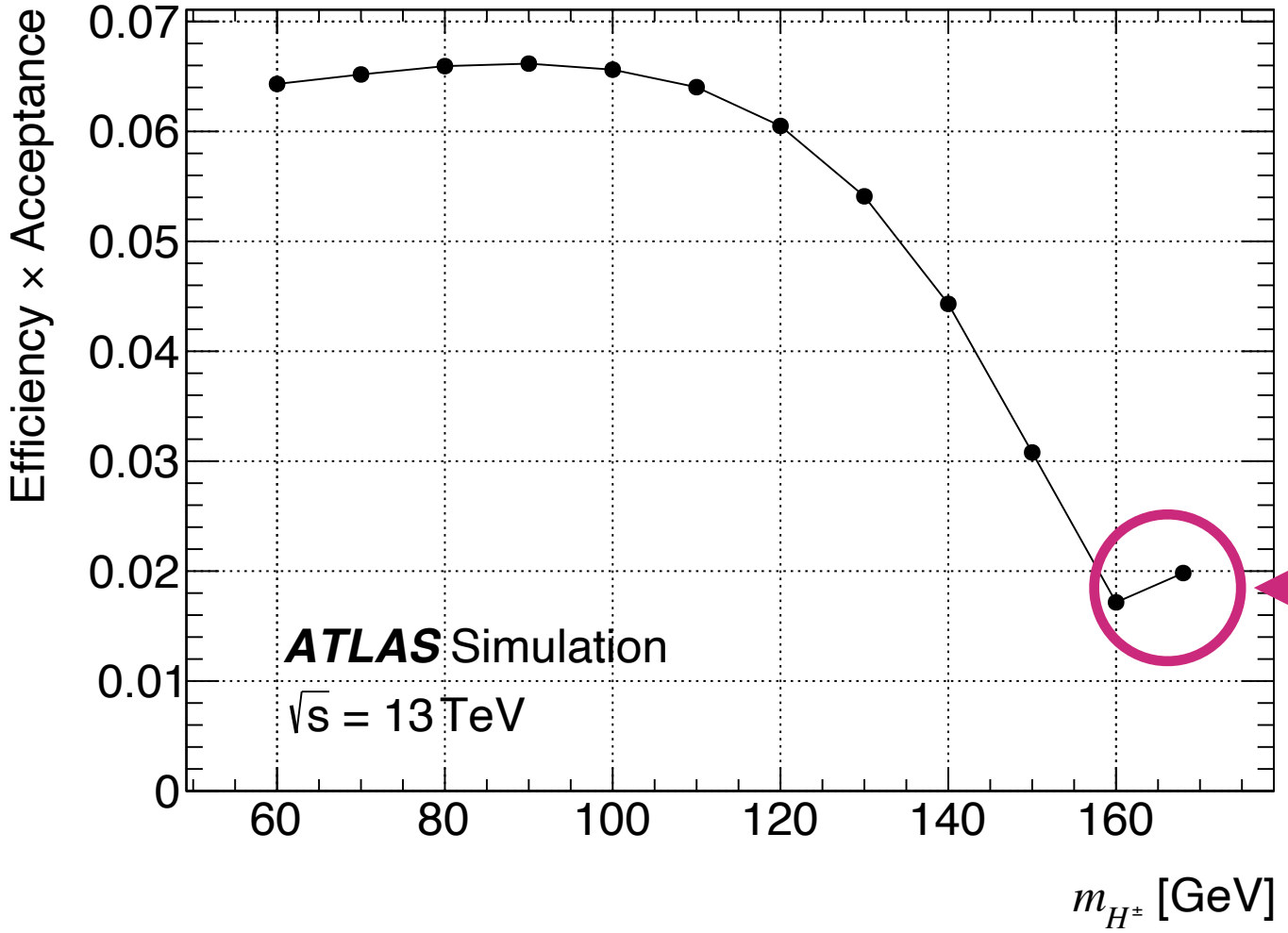
- Very diverse set of results
- From precision measurements to HHH searches
- 3 re-analyses of Run 2 data included, with impressive improvements
- Luminosity jump from Run 2 to Run 3 relatively much smaller than from Run 1 to Run 2
  ⇒ Finding new (better) solutions to old problems is a necessity!
- Recent ATLAS results show importance of novel techniques
- Example: Evolution of μ_{HH} limits in $HH \rightarrow bb\tau\tau$



See A. Wang's talk on HL-LHC projections on Wednesday

Thank you!

$H^+ \to c\bar{s}$: Signal $A \times \epsilon$



Higher contribution from off-shell top