
Status and Plan of HHML

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HH → Multilepton Channel

- Several HH decay modes with small branching ratios are included: $VVVV$, $VV\gamma\gamma$, $VV\tau\tau$, $\tau\tau\tau\tau$, $bbZZ$
- ~6.5% of HH events decay to final states where the HH system cannot be fully reconstructed and none of these are covered by dedicated analyses.
- Use *a common analysis strategy* for the same final states

BR (%)	bb	WW	$\tau\tau$	ZZ	$\gamma\gamma$
bb	34				
WW	25	4.6			
$\tau\tau$	7.3	2.7	0.39		
ZZ	3.1	1.1	0.33	0.069	
$\gamma\gamma$	0.26	0.10	0.028	0.012	0.00005

- Run2 Glance [\[link\]](#)
- Run2 INT note [\[link\]](#)
- Run2 Paper [\[10.1007/JHEP08\(2024\)164\]](#)

Analysis Team

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Editorial Board

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Otilia Ducu (chair), Olivier Arnaez, Jason Veatch

Run 2 → Run 3



HHML



HIGP

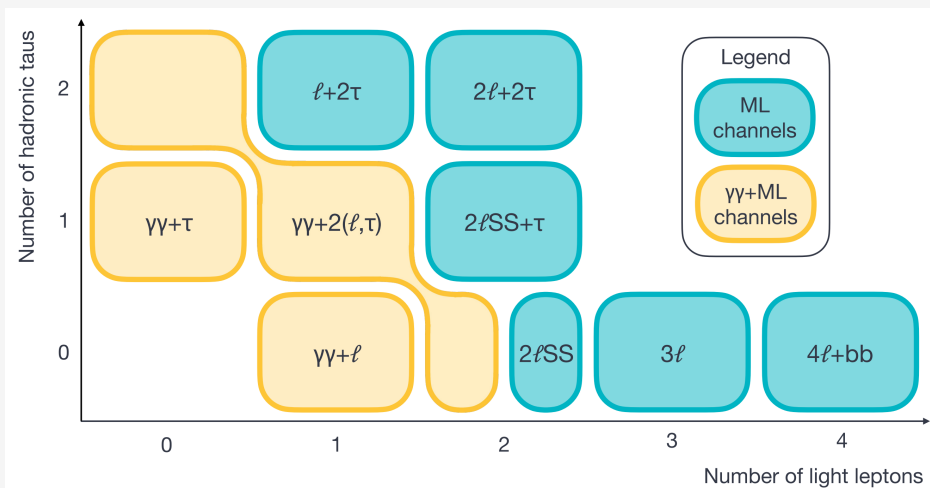


NRML
(HWW + HHML)

Run 2 → Run 3

- $2\ell SS 0\tau_h$ and $2\ell SS + 1\tau_h$
- $3\ell \rightarrow$ **most sensitive channel** (μ_{HH})
- $1/2\ell + 2\tau$
- $b\bar{b}4\ell \rightarrow$ **most sensitive channel** (κ_λ)

- Two photons with leptons and τ_h :
 - $\gamma\gamma + 1\ell 0\tau, \gamma\gamma + 0\ell 1\tau, \gamma\gamma + 2\ell$

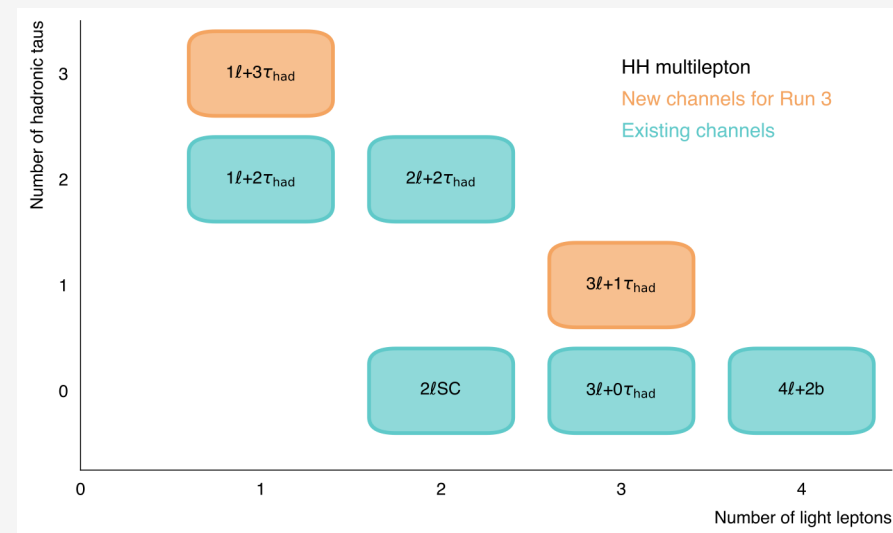


Run 2 + partial Run 3 (**140 fb^{-1}** + **2022-2024, 159 fb^{-1}**)

- ATLAS Glance [\[link\]](#)
- INT Note [\[CDS\]](#)
- EB Request meeting [\[link\]](#)
- Target: **Moriond 2027**

- $2\ell SC, 3\ell, 1/2\ell + 2\tau, b\bar{b}4\ell$
- $2\ell SS + 1\tau_h$ dropped due to low sensitivity

- Two new channels from CMS HHML: **$3\ell 1\tau_h$** and **$1\ell 3\tau_h$**



Team Composition

Channels	Person power (Chinese)
$4\ell + b\bar{b}$	NJU + IHEP: Fabio, Yanping, Yixiang
3ℓ	SJTU: Cen, Liang
$2\ell SC$	UW + IHEP + Cambridge: Yulei, Shudong, Shuhui
$3\ell + \tau$	SJTU: Jiahui, Xiang, Liang
$1/2\ell + 2\tau$	-
$1\ell + 3\tau$	UC Santa Cruz: Alex Zeng Wang, Dongyi Liu
Combination	TECHNION: Danning Liu

Analysis Strategy



- Background Modelling:
 - Irreducible backgrounds: MC (with **data-driven corrections** in CR if dominant)
 - Fake backgrounds:
 - **Template Fit** (TF) for fake light leptons
 - **Fake Factor** (FF) for fake taus
- Multivariate Analysis:
 - Transformers for $2\ell SC$ and 3ℓ
 - XGBoost for τ channels and $bb4\ell$
 - 3-fold training to avoid bias

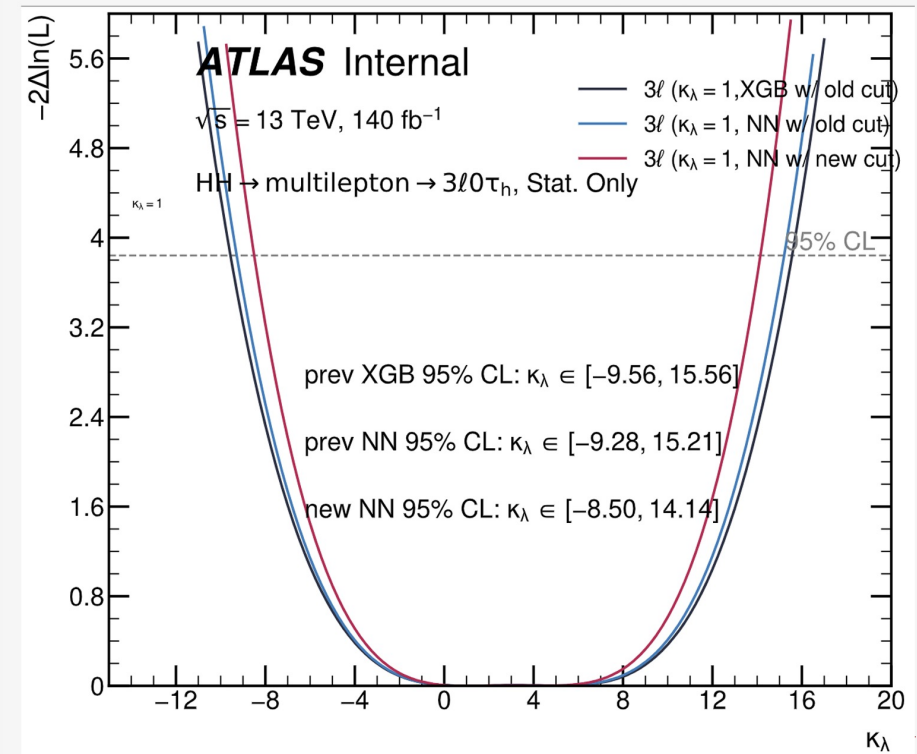
Channels	Dominant backgrounds
$4\ell + b\bar{b}$	$t\bar{t}$, ttV , $Z + \text{jets}$, single Higgs, VV
3ℓ	WZ , fake lepton
$2\ell SC$	VV , QMisID, fake lepton
$3\ell + \tau$	ZZ , WZ , fake tau
$1/2\ell + 2\tau$	VV , fake tau
$1\ell + 3\tau$	fake tau

Key Improvements (1)

- 3ℓ : Optimize cutflow to increase the efficiency of $\kappa_\lambda = 5$ sample by **Cen (SJTU)** [\[link\]](#)
 - Cut $|m_{\ell\ell\ell} - m_Z| > 10$ GeV has been removed
 - **10% improvement** on κ_λ scan interval

$\sqrt{s}=13$ TeV, $L=140$ fb $^{-1}$ 3ℓ (Run~2)	ggF SM HH	HH $\kappa_\lambda=0$	HH $\kappa_\lambda=5$	HH $\kappa_\lambda = 0 / 1$	HH $\kappa_\lambda = 5 / 1$
Inclusive (3ℓ)	4.62 $\pm$ 0.01	10.01 $\pm$ 0.02	11.74 $\pm$ 0.02	2.17 $\pm$ 0.01	2.54 $\pm$ 0.01
Baseline 3ℓ selection	4.62 $\pm$ 0.01	10.01 $\pm$ 0.02	11.74 $\pm$ 0.02	2.17 $\pm$ 0.01	2.54 $\pm$ 0.01
Trigger selection	4.62 $\pm$ 0.01	10.01 $\pm$ 0.02	11.74 $\pm$ 0.02	2.17 $\pm$ 0.01	2.54 $\pm$ 0.01
Lepton1 pt > 10 GeV	4.62 $\pm$ 0.01	10.01 $\pm$ 0.02	11.74 $\pm$ 0.02	2.17 $\pm$ 0.01	2.54 $\pm$ 0.01
Lepton2 pt > 15 GeV	4.26 $\pm$ 0.01	9.18 $\pm$ 0.02	10.60 $\pm$ 0.02	2.16 $\pm$ 0.01	2.49 $\pm$ 0.01
Lepton3 pt > 15 GeV	3.87 $\pm$ 0.01	8.30 $\pm$ 0.02	9.38 $\pm$ 0.02	2.14 $\pm$ 0.01	2.42 $\pm$ 0.01
Low mass veto	3.87 $\pm$ 0.01	8.29 $\pm$ 0.02	9.38 $\pm$ 0.02	2.14 $\pm$ 0.01	2.42 $\pm$ 0.01
SR - nJets $\geq$ 1	3.35 $\pm$ 0.01	7.12 $\pm$ 0.02	7.74 $\pm$ 0.02	2.12 $\pm$ 0.01	2.31 $\pm$ 0.01
SR - nBJets == 0	2.74 $\pm$ 0.01	5.84 $\pm$ 0.02	6.33 $\pm$ 0.02	2.13 $\pm$ 0.01	2.31 $\pm$ 0.01
SR - Z mass veto	2.25 $\pm$ 0.01	4.78 $\pm$ 0.02	5.16 $\pm$ 0.02	2.12 $\pm$ 0.01	2.29 $\pm$ 0.01
SR - MHZ Z mass veto	1.98 $\pm$ 0.01	4.10 $\pm$ 0.01	3.92 $\pm$ 0.01	2.07 $\pm$ 0.01	1.98 $\pm$ 0.01
SR - Leptons Tight ID and Iso	1.35 $\pm$ 0.01	2.76 $\pm$ 0.01	2.50 $\pm$ 0.01	2.04 $\pm$ 0.01	1.85 $\pm$ 0.01
SR - nJets $\geq$ 1	1.35 $\pm$ 0.01	2.76 $\pm$ 0.01	2.50 $\pm$ 0.01	2.04 $\pm$ 0.01	1.85 $\pm$ 0.01

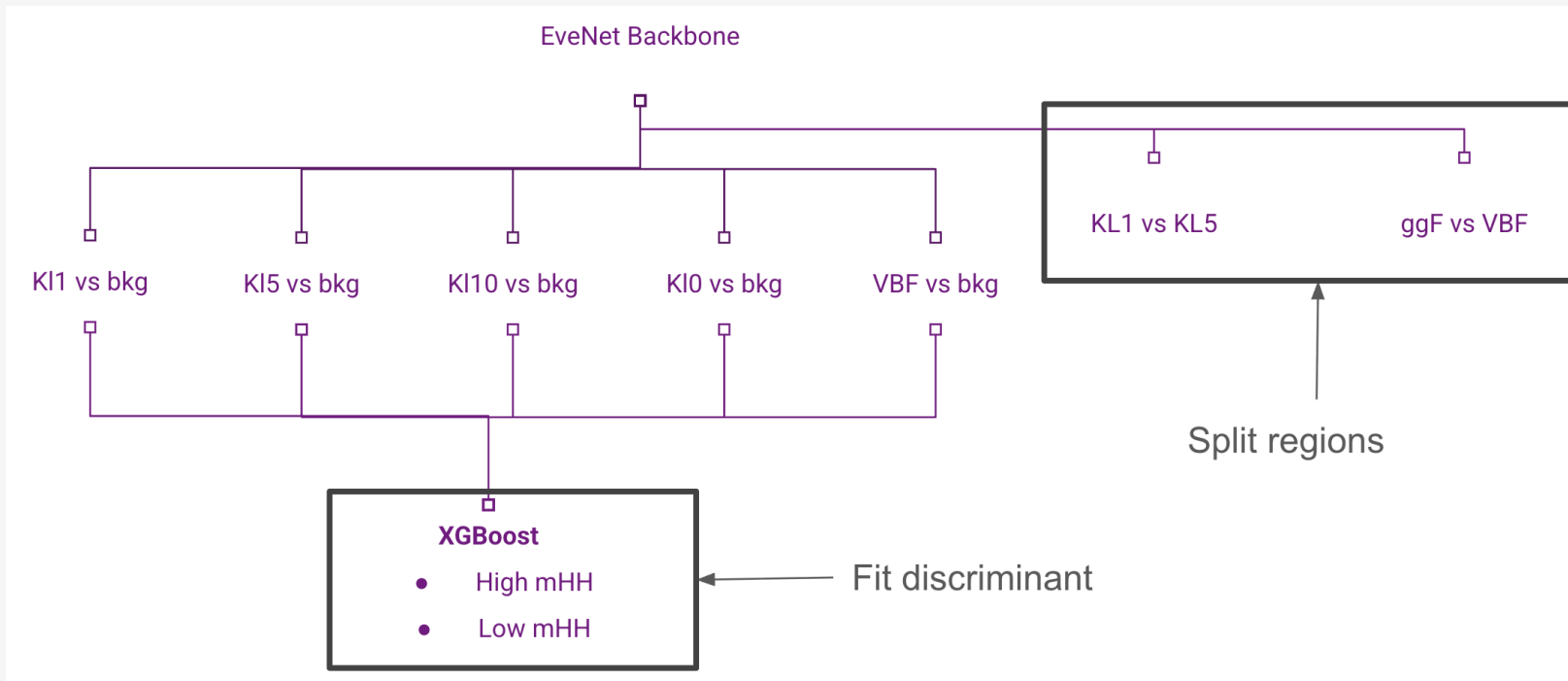
$\sqrt{s}=13$ TeV, $L=140$ fb $^{-1}$ 3ℓ (Run~2)	ggF SM HH	HH $\kappa_\lambda=0$	HH $\kappa_\lambda=5$	HH $\kappa_\lambda = 0 / 1$	HH $\kappa_\lambda = 5 / 1$
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Lepton1 pt > 10 GeV	4.62 $\pm$ 0.01	10.01 $\pm$ 0.02	11.74 $\pm$ 0.02	2.17 $\pm$ 0.01	2.54 $\pm$ 0.01
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Lepton3 pt > 15 GeV	3.87 $\pm$ 0.01	8.30 $\pm$ 0.02	9.38 $\pm$ 0.02	2.14 $\pm$ 0.01	2.42 $\pm$ 0.01
Low mass veto	3.87 $\pm$ 0.01	8.29 $\pm$ 0.02	9.38 $\pm$ 0.02	2.14 $\pm$ 0.01	2.42 $\pm$ 0.01
SR - nBJets == 0	3.26 $\pm$ 0.01	7.02 $\pm$ 0.02	7.97 $\pm$ 0.02	2.15 $\pm$ 0.01	2.44 $\pm$ 0.01
SR - Z mass veto	2.70 $\pm$ 0.01	5.77 $\pm$ 0.02	6.52 $\pm$ 0.02	2.14 $\pm$ 0.01	2.42 $\pm$ 0.01
SR - I2 and I3 are not ExtConv	2.68 $\pm$ 0.01	5.73 $\pm$ 0.02	6.49 $\pm$ 0.02	2.14 $\pm$ 0.01	2.42 $\pm$ 0.01
SR - Leptons Tight ID and Iso	1.81 $\pm$ 0.01	3.80 $\pm$ 0.01	4.08 $\pm$ 0.01	2.10 $\pm$ 0.01	2.26 $\pm$ 0.01
SR Final Yields	1.81 $\pm$ 0.01	3.80 $\pm$ 0.01	4.08 $\pm$ 0.01	2.10 $\pm$ 0.01	2.26 $\pm$ 0.01
SR - High Jet region	0.91 $\pm$ 0.00	1.87 $\pm$ 0.01	1.87 $\pm$ 0.01	2.05 $\pm$ 0.02	2.04 $\pm$ 0.02
SR - Low Jet region	0.89 $\pm$ 0.00	1.93 $\pm$ 0.01	2.21 $\pm$ 0.01	2.16 $\pm$ 0.02	2.48 $\pm$ 0.02



Key Improvements (2)

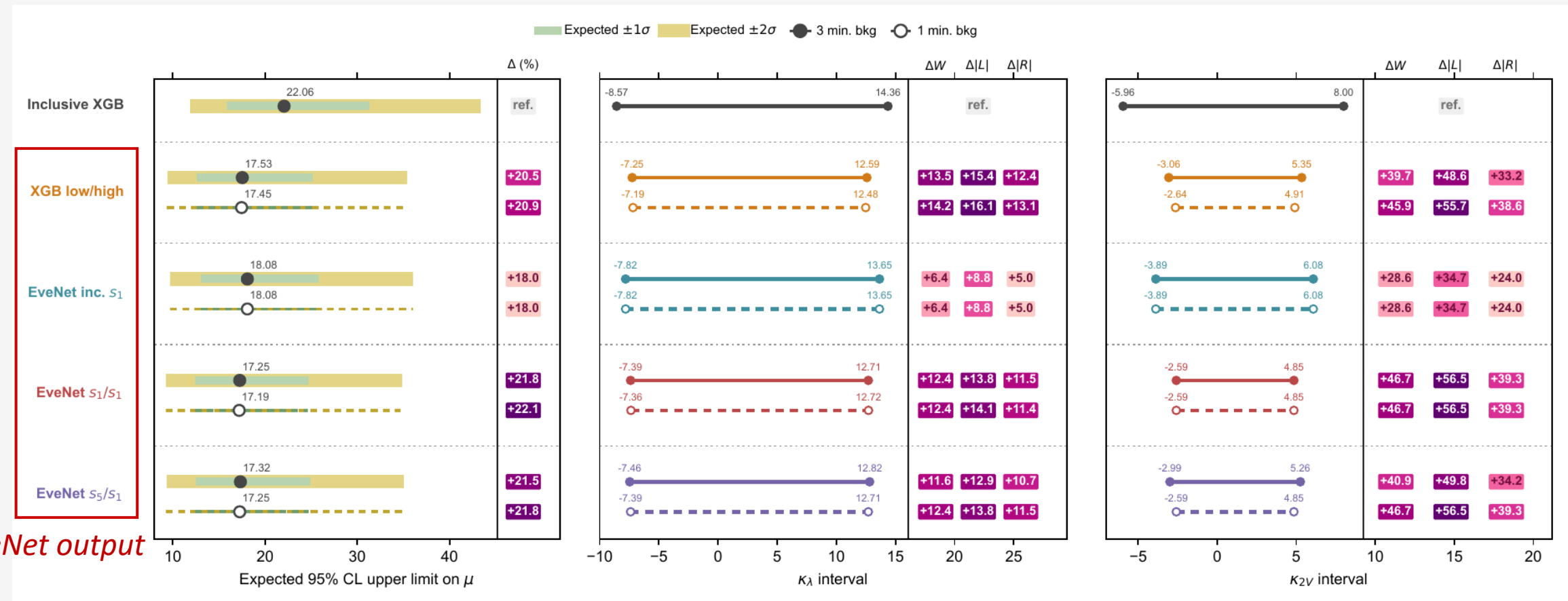
- 3ℓ & $2\ell SC$: an advanced transformer-based ML model [[EveNet](#)] for better S/B by **Yulei (UW)**
 - EveNet: A foundation model with reusable backbone and shared representation [[ICHEP](#)]

2ISC network structure



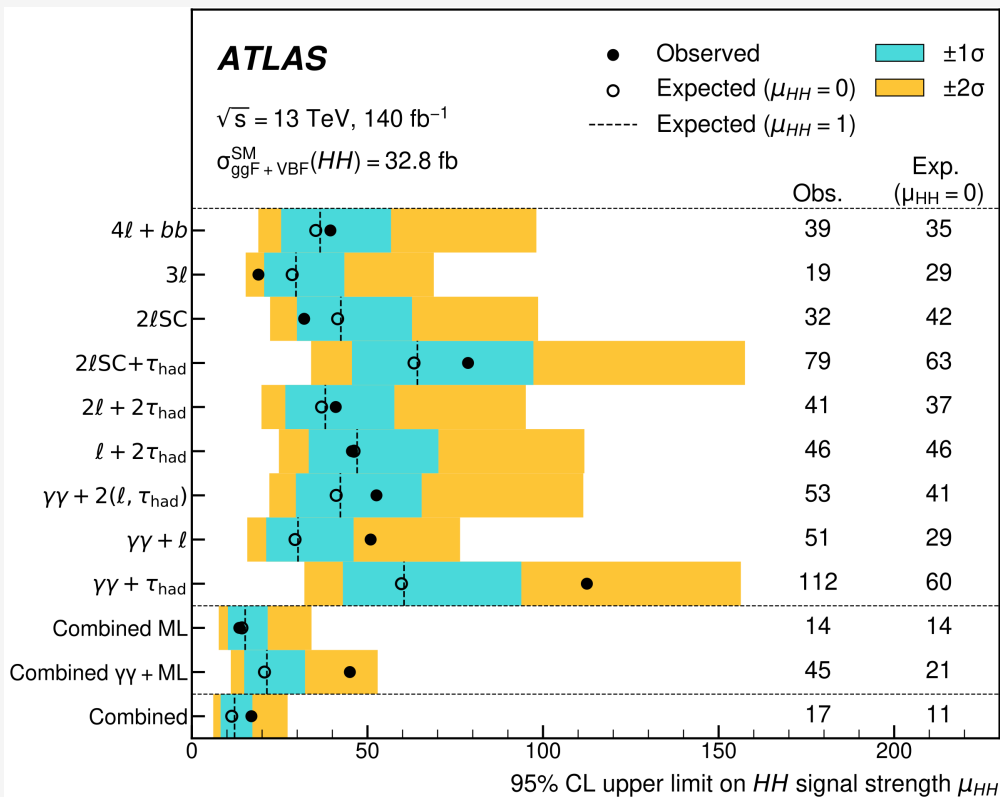
Key Improvements (2)

- 3ℓ & $2\ell SC$: an advanced transformer-based ML model [[EveNet](#)] for better S/B
 - For 2LSC, **$\sim 21\%$** gain on μ_{HH} , **$\sim 13\%$** gain on κ_λ interval, and **$\sim 45\%$** gain on κ_{2V} interval (compared with retrained XGB)

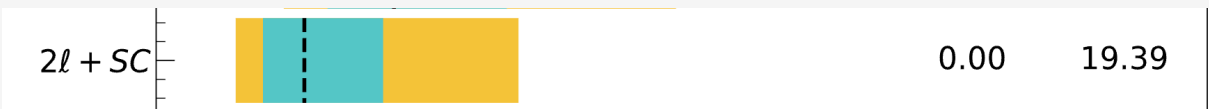


Key Improvements (2)

- 3ℓ & $2\ell SC$: an advanced transformer-based ML model [EveNet] for better S/B
 - For 2LSC, $\sim 50\%$ improvement on μ_{HH} (**42 $\rightarrow$ ~ 20**)



Current Run 2 results (Full Syst)

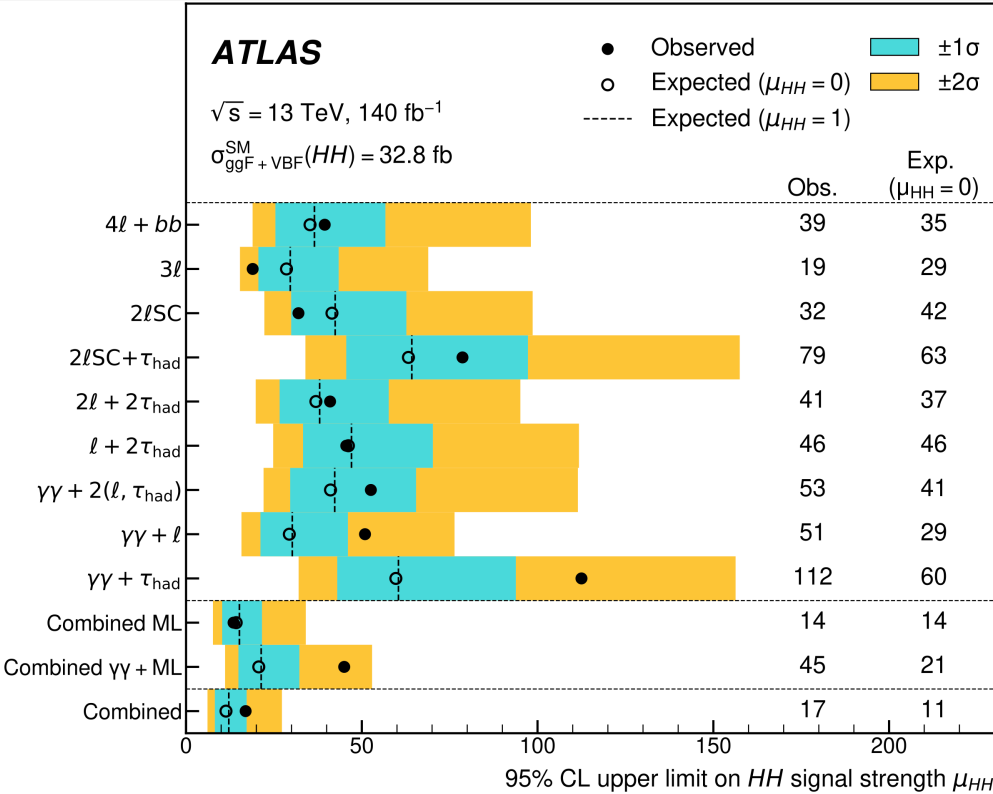


Key Improvements (3)

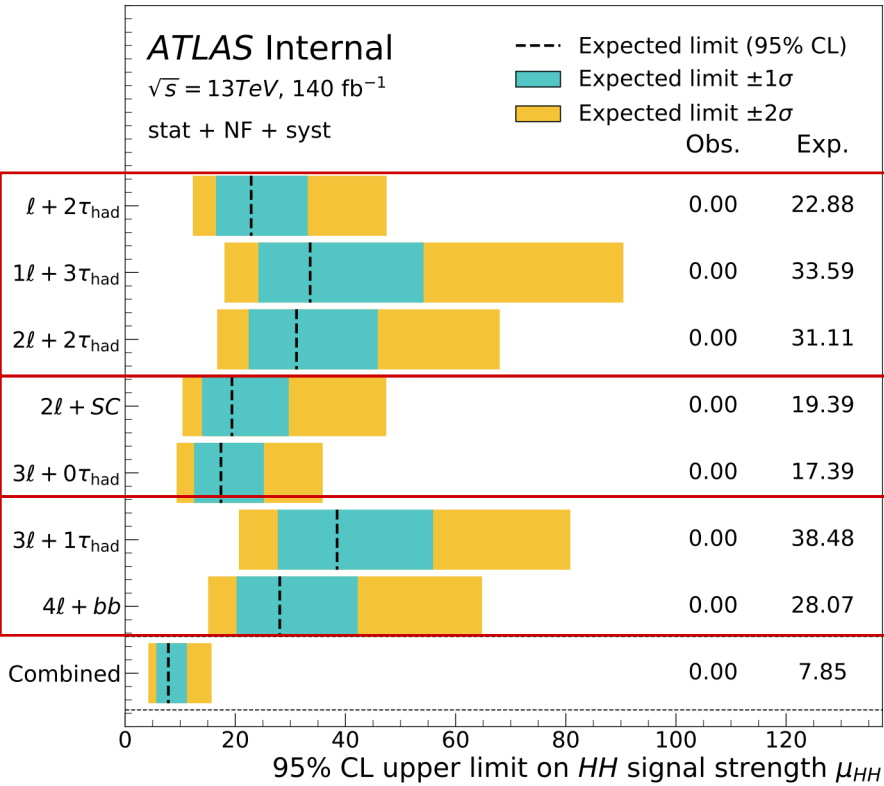
- Including Tau triggers (LTT, STT, DTT) by **Cen (SJTU)** and **Dongyi (UC Santa Cruz)**
 - Still under investigation...potential gain from STT and DTT
- $3\ell 1\tau$ and $1\ell 3\tau$: two new added channels in this round
 - Studied by **the SJTU team (Jiahui, Xiang)** and **UC Santa Cruz team (Dongyi, Alex Zeng Wang)**
 - Fake factor derived by 2 tau channels has been shared across all tau channels
- $bb4\ell$: better fake lepton estimation using fake factor method by **NJU + IHEP team (Fabio)**
 - In progress...

Re-optimizing Run2

10.1007/JHEP08(2024)164



EB Request version



Stat. only

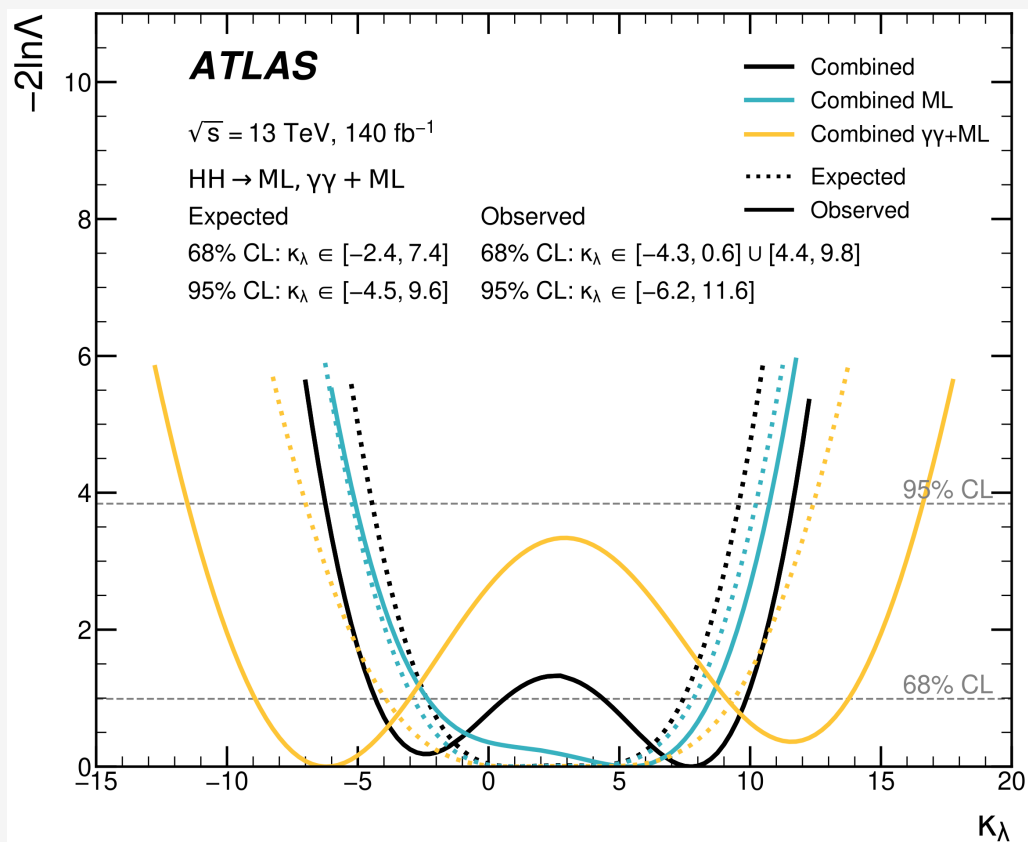
Full syst.

Stats + NF

$\mu_{HH}: 14 \rightarrow 8$ (43%)

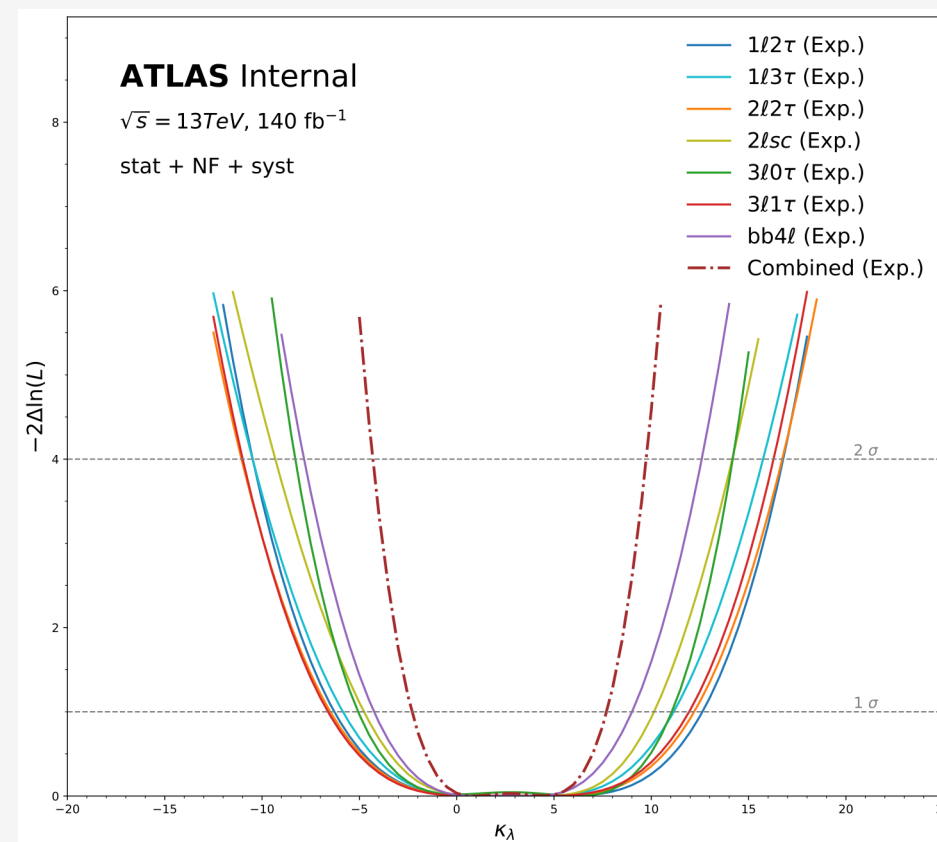
Re-optimizing Run2

[10.1007/JHEP08\(2024\)164](#)



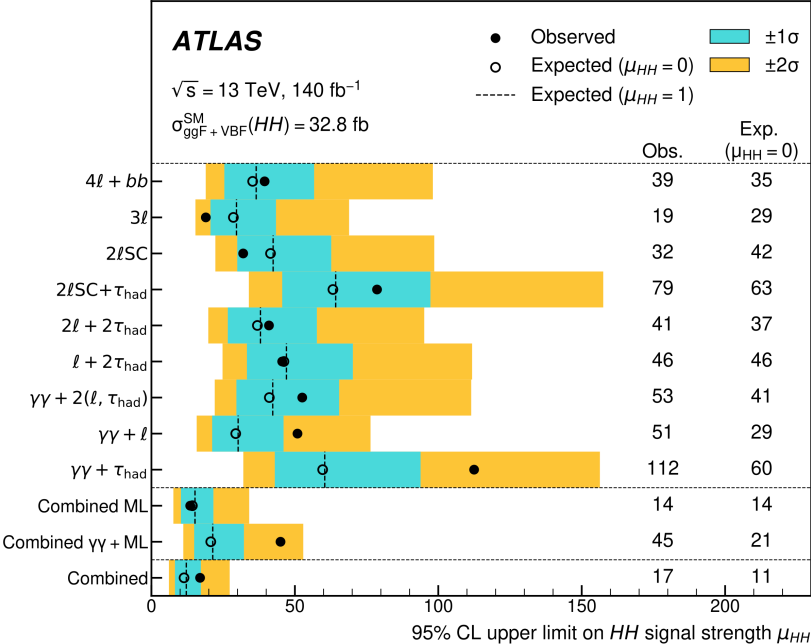
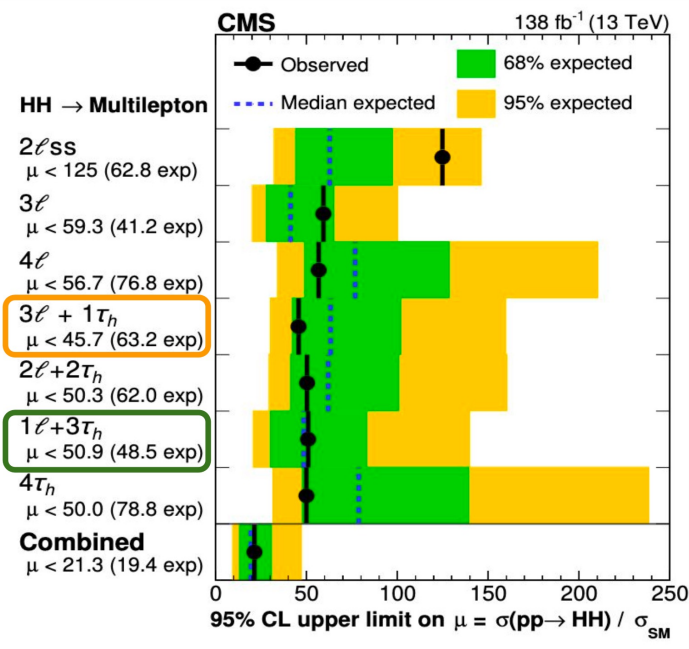
From stat only case: driven by $2\ell SC$ and $bb4\ell$

EB Request version

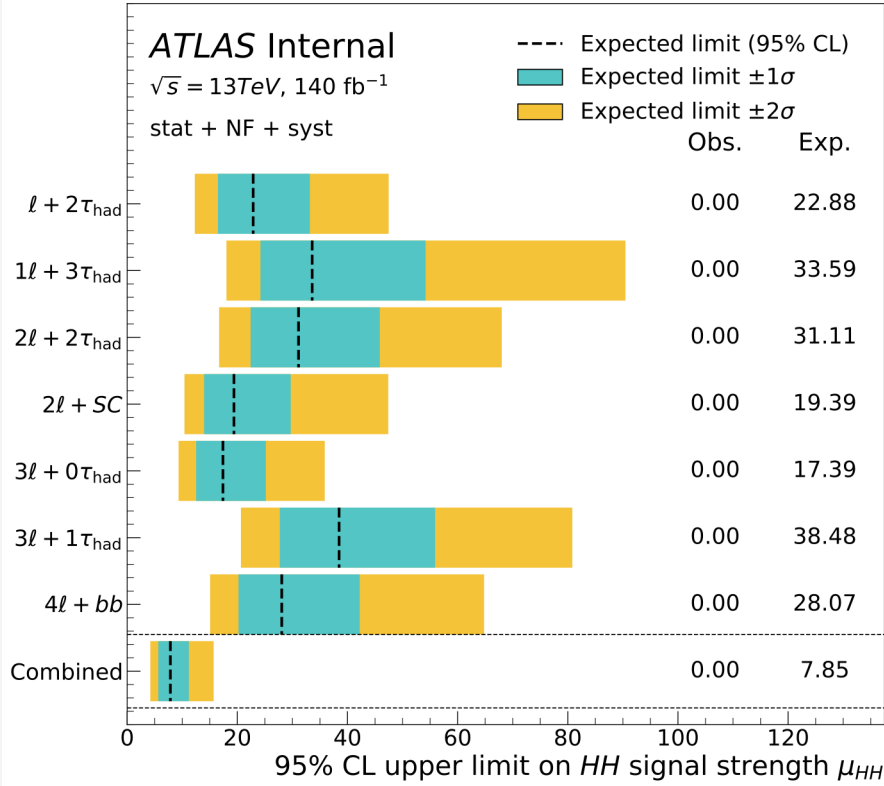


$2\sigma: [-4.2, 9.7]$

Run2 Comparison

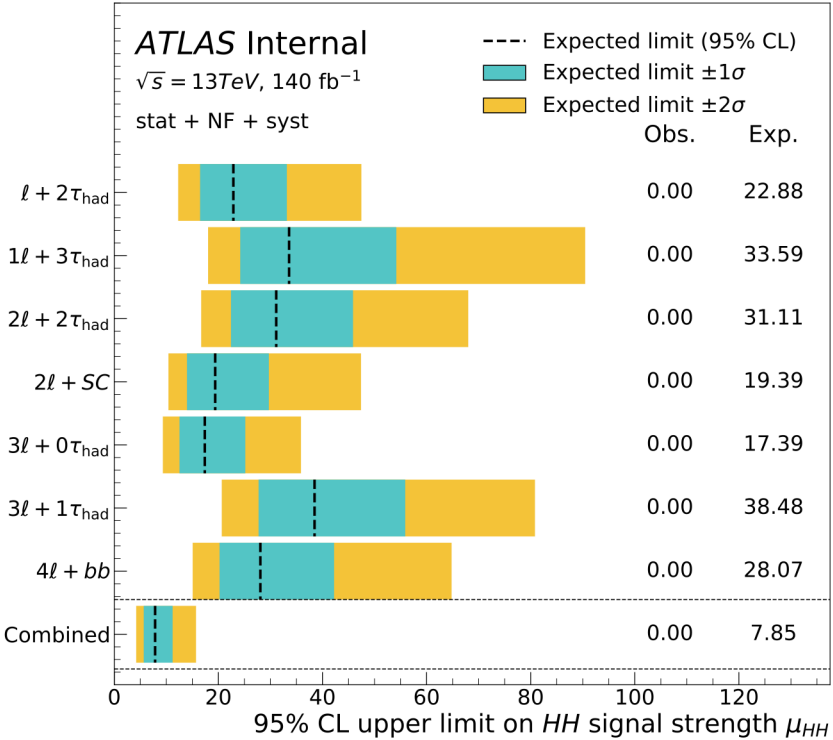


EB Request version

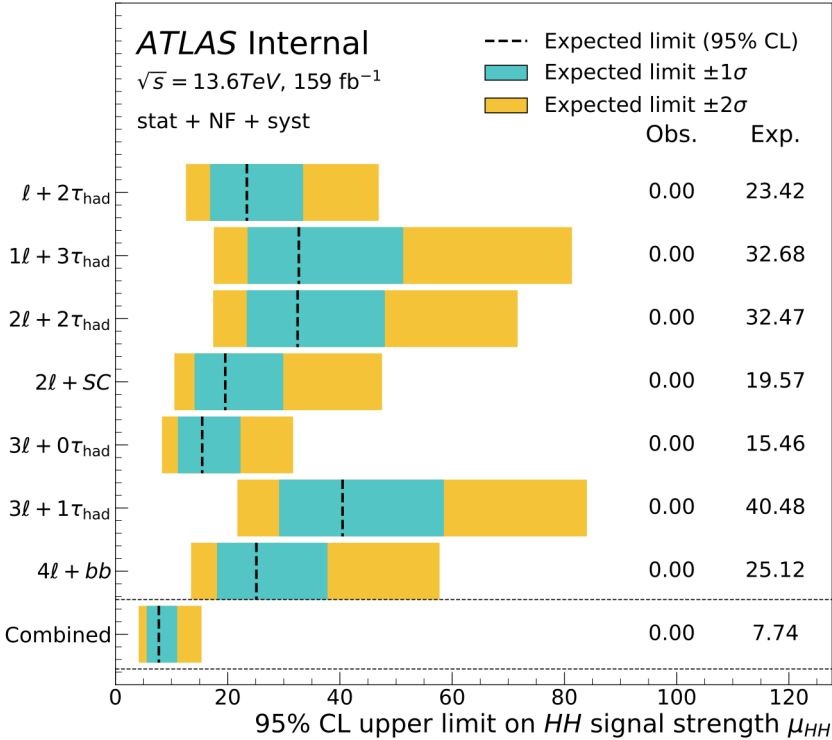


Run 2 + Run 3 (μ_{HH})

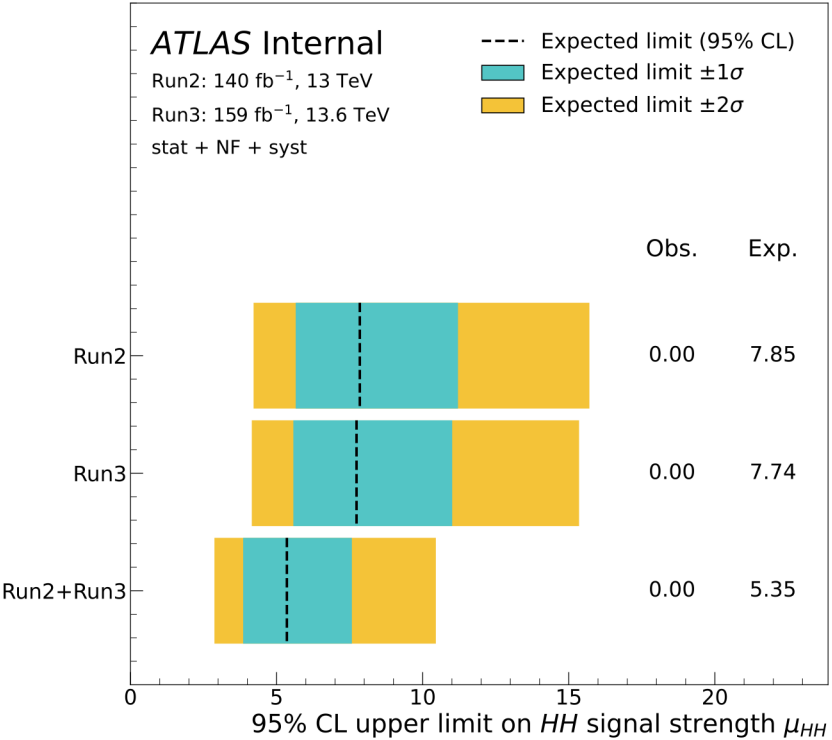
Run2



Run3

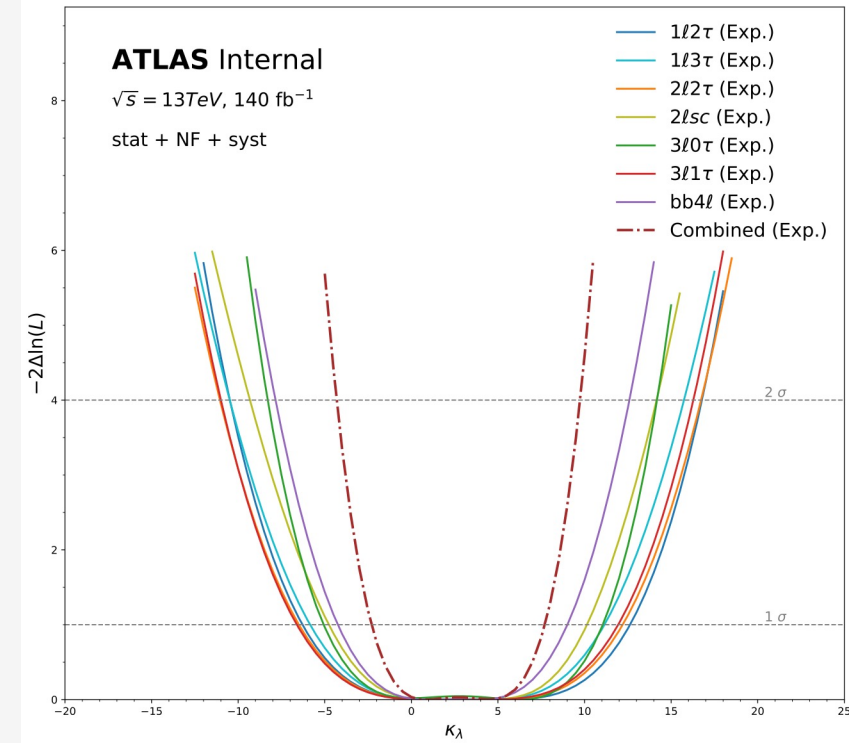


Run2 + Run3



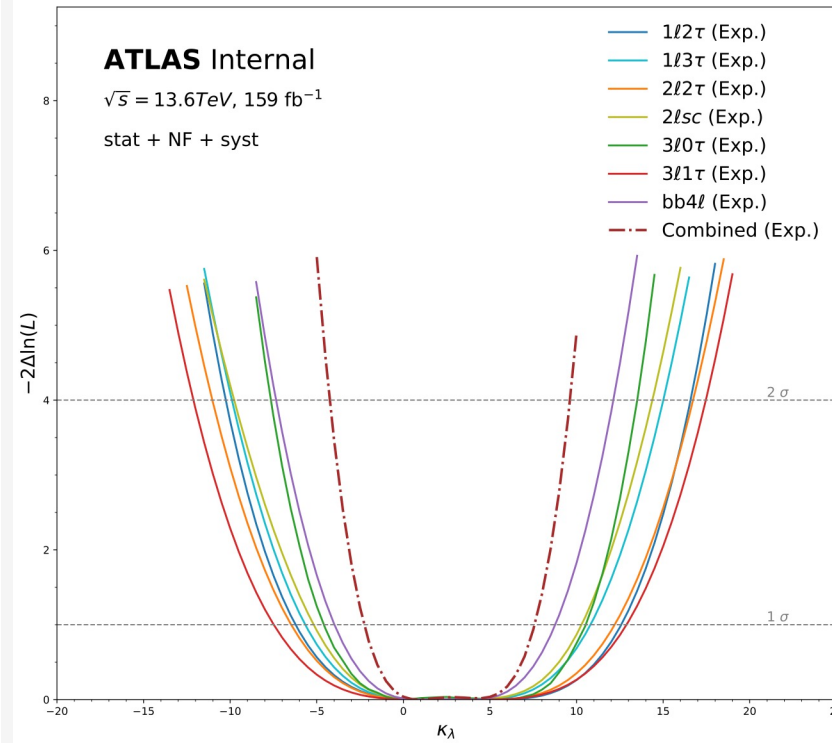
Run 2 + Run 3 (κ_λ)

Run2



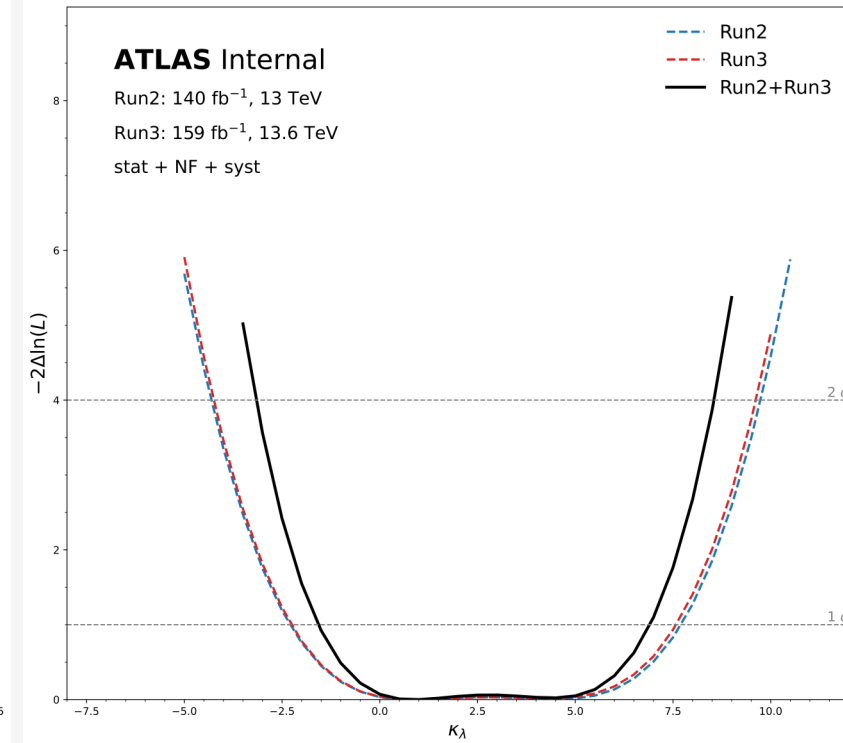
$2\sigma: [-4.2, 9.7]$

Run3



$2\sigma: [-4.2, 9.6]$

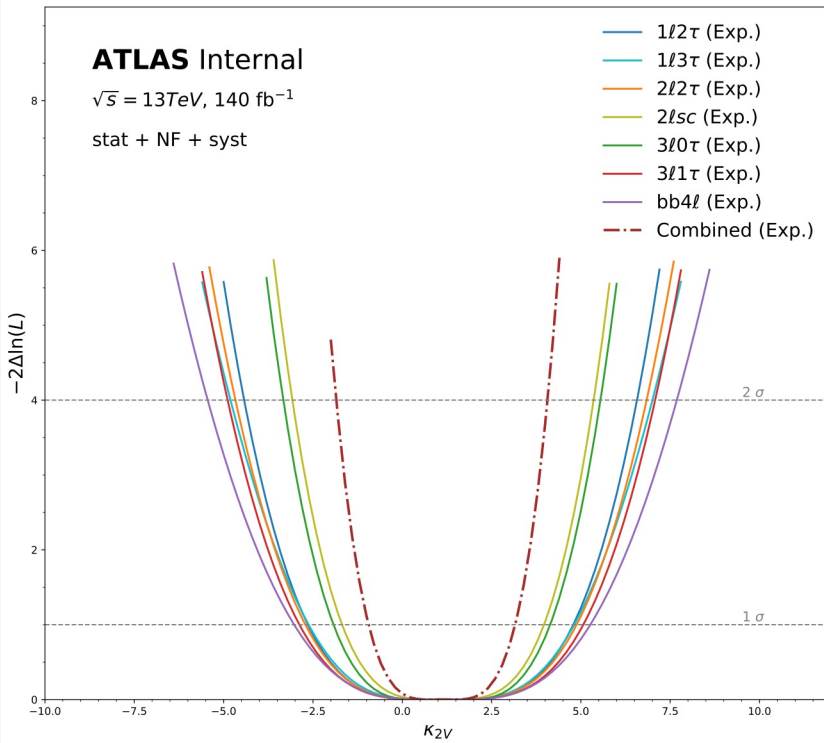
Run2 + Run3



$2\sigma: [-3.1, 8.5]$

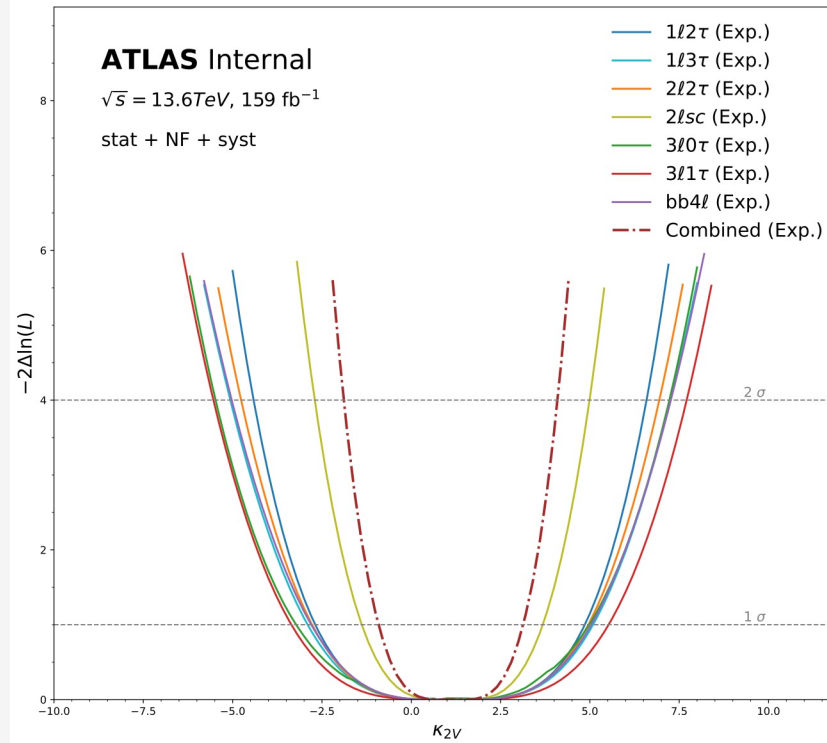
Run 2 + Run 3 (κ_{2V})

Run2



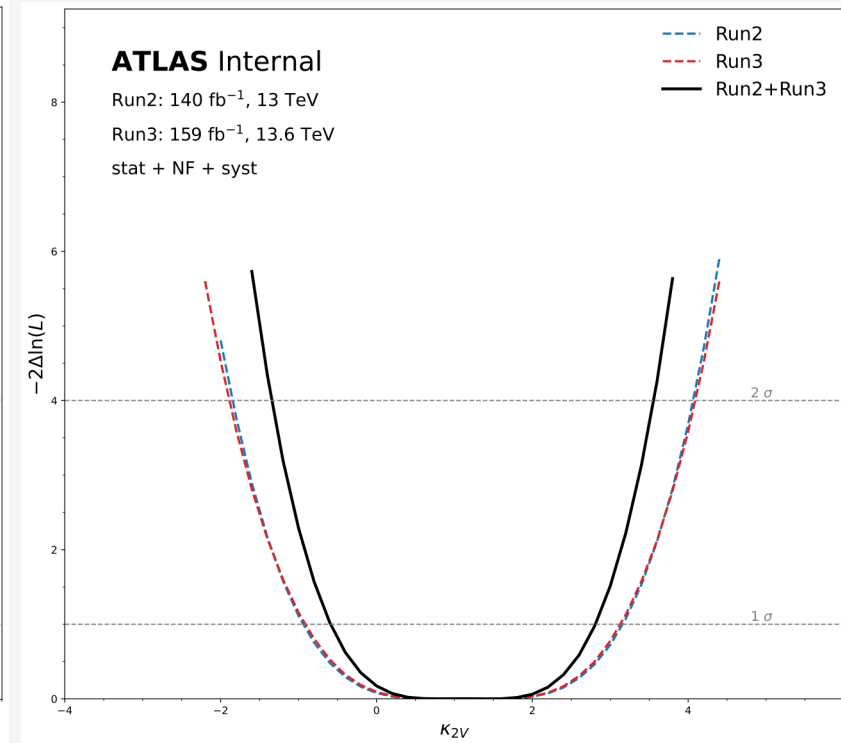
$2\sigma: [-1.8, 4.0]$

Run3



$2\sigma: [-1.9, 4.1]$

Run2 + Run3



$2\sigma: [-1.3, 3.5]$

To-do and Plan

- Finalize the Run2 + partial Run3 HHML Analysis
 - *Target: Moriond 2027*
 - *Status: EB requested*
 - New NTuple productions with small syst bugs fixed, also with alternative signal samples for PS
 - Implement systematics for tau channels
 - Finalize fake lepton estimation for $bb4\ell$
 - (More optimizations on Machine Learning strategy...)
 - To be included in the **next round** HH combination (Moriond 2027)
- Run2 + Full Run3 HHML Analysis...
 - Too early for now 🤔

Summary

- 95% C.L. combined expected upper limit reaches 5 on the HH cross-section over SM for $HH \rightarrow$ multilepton final states with the full Run 2 data (140 fb^{-1}) and partial Run 3 data (159 fb^{-1}) 🥳
 - **~64%** gain on μ_{HH} ($14 \rightarrow 5$)
 - **~25%** gain on κ_λ interval ($[-5.2, 10.2] \rightarrow [-3.1, 8.5]$) *Compared with previous publication*
 - **~25%** gain on κ_{2V} interval ($[-2.1, 4.3] \rightarrow [-1.3, 3.5]$)
 - Latest results by **Danning**: <https://hhml-combination.web.cern.ch/>
- Chinese teams play the dominant roles for HHML analysis
 - **Analysis Contact**: Yulei Zhang (UW)
 - **INT note editor**: Cen Mo (SJTU)
 - **EB request talk**: Alex Zeng Wang (UC Santa Cruz)
 - **Status reports on NRML plenary**: 4/6 (Danning, Dongyi, Shudong, Cen)
 - Several key improvements led by Chinese teams (cutflows, ML models, new channels, ...)

Summary

- Chinese plays the dominant roles beyond HHML in Non-Resonant Multilepton (NRML) subgroup
 - **Subgroup Convenor:** Yulei Zhang (UW), Jiayi Chen (SFU)
 - **HWW ggF & VBF measurement AC:** Yifan Zhu (SJTU/TDLI)
 - **HWW $l\nu l\nu$ QE measurement AC :** Danning Liu (Technion)
 - **HWW $l\nu cs$ QE measurement AC:** Ang Li (BNL)