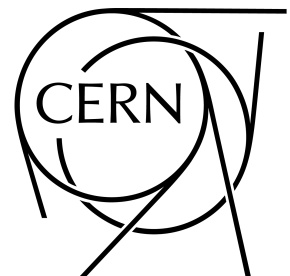


4D Tracking in ATLAS

4D Tracking Meeting, 12th Jan 2022



Valentina & Ariel

SLAC

Recap

- Recap from our previous discussion in September:
<https://indico.slac.stanford.edu/event/7061/>
- Produce **ATLAS samples** (ITk+HGTD scenario) containing **tracks with decorated time information**
 - <https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/4DPreliminaryInvestigation>

4DPreliminaryInvestigation

- ↓ [Introduction](#)
- ↓ [Instructions for rel. 21.9](#)
- ↓ [Presentations](#)

Not yet
Certified as
ATLAS
Documentation

Responsible:
[ValentinaCairo](#), [ArielSchwartzman](#)

Introduction

This page will collect studies (and the related technical information) about the 4D tracking investigation for a potential ITk upgrade to complement the functionalities of the HGTD. If you have questions, please contact valentina.maria.cairo@cern.ch and ariel.schwartzman@cern.ch.

- Next steps:
 - check impact on **b-tagging** → direct connection to **physics cases**
 - **Work has started!**

Recap

- **HH** & VBF H→inv are definitely of interest in this group!
- **H→yy** and **VBF H→tautau** could be very good additions!
- **From CMS MTD TDR:** “The MTD will give timing information for MIPs with 30–40 ps resolution at the beginning of HL-LHC operation in 2026, degrading slowly as a result of radiation damage to 50–60 ps by the end of HL-LHC operations.”
- $21.2 \times 42 \text{ mm}^2$ with square pixels of $1.3 \times 1.3 \text{ mm}^2$.

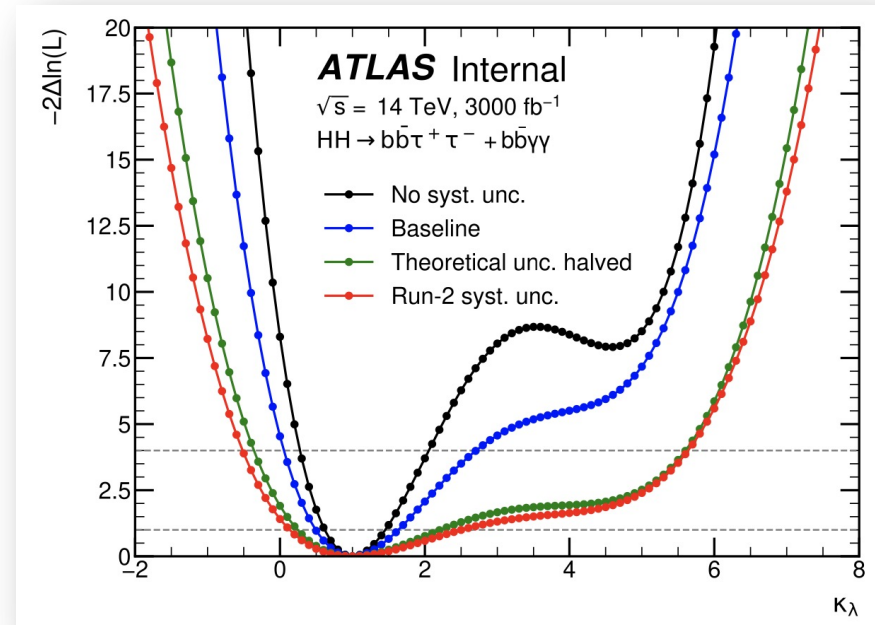
Table 1.1: Expected scientific impact of the MIP Timing Detector, taken from Ref. [8].

Signal	Physics measurement	MTD impact
H → $\gamma\gamma$ and H→4 leptons	+15–25% (statistical) precision on the cross section → Improve coupling measurements	Isolation and Vertex identification
VBF→H→ $\tau\tau$	+30% (statistical) precision on cross section → Improve coupling measurements	Isolation VBF tagging, p_T^{miss}
HH	+20% gain in signal yield → Consolidate searches	Isolation b-tagging
EWK SUSY	+40% background reduction → 150 GeV increase in mass reach	MET b-tagging
Long-lived particles (LLP)	Peaking mass reconstruction → Unique discovery potential	β_{LLP} from timing of displaced vertices

about 200. The integrated luminosity \times efficiency is increased and this gain is equivalent to collecting data for three additional years beyond the ten year run planned for the HL-LHC.

HL-LHC Extrapolations for HH searches

- Various systematics scenarios studied for $HH \rightarrow \gamma\gamma b\bar{b}$ and $HH \rightarrow b\bar{b}\tau^+\tau^-$ and full Run 2 results extrapolated to HL-LHC $\int L$
- Preliminary [combination](#) studies available, note in preparation



Old HL-LHC projections

Channel	Statistical-only	Statistical + Systematic
$HH \rightarrow b\bar{b}b\bar{b}$	1.2	0.5
$HH \rightarrow b\bar{b}\tau^+\tau^-$	2.3	2.0
$HH \rightarrow b\bar{b}\gamma\gamma$	2.1	2.0
Combined	3.3	2.9

ATL-PHYS-PUB-2020-005

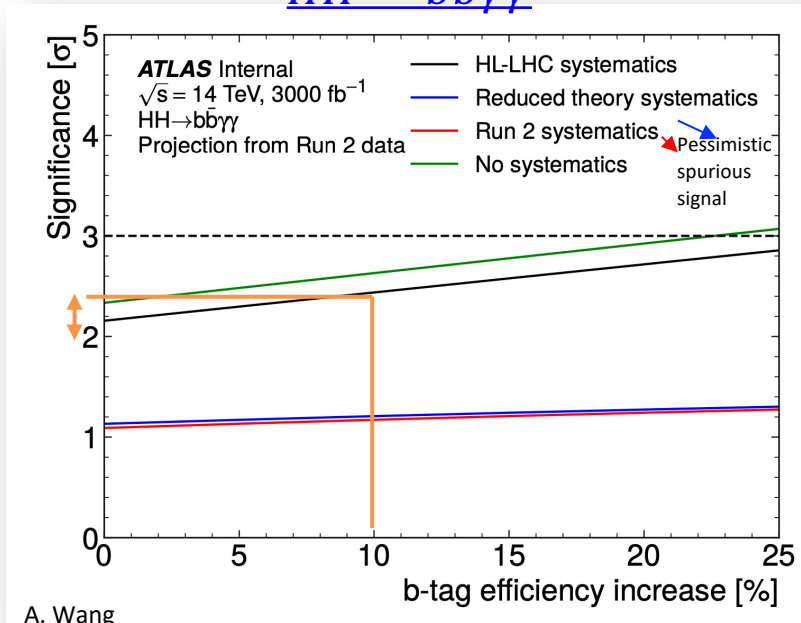
New HL-LHC projections

Expected significance	$b\bar{b}\tau^+\tau^-$	$b\bar{b}\gamma\gamma$	Combined
Stat only	3.97	2.33	4.60
Baseline	2.76	2.16	3.22
Reduced theory systematics	1.70	1.14	2.00
Run 2 systematics	1.50	1.10	1.73

How to boost analysis sensitivity in HL-LHC?

Reduce systematics, increase signal efficiency for instance via improved object reconstruction!

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

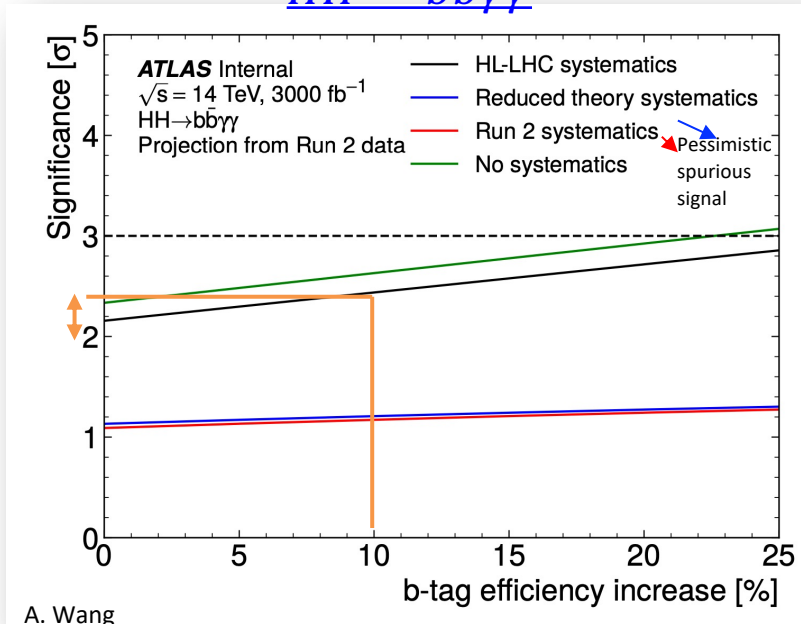


- Run2-like systematics would wash out b-tagging improvements!
- But... a hypothetical **10% improvement in btag. eff.** with HL-LHC systematics would buy us **$\sim 0.3 \sigma$** , i.e. $\sim 500 \text{ fb}^{-1}$!!!

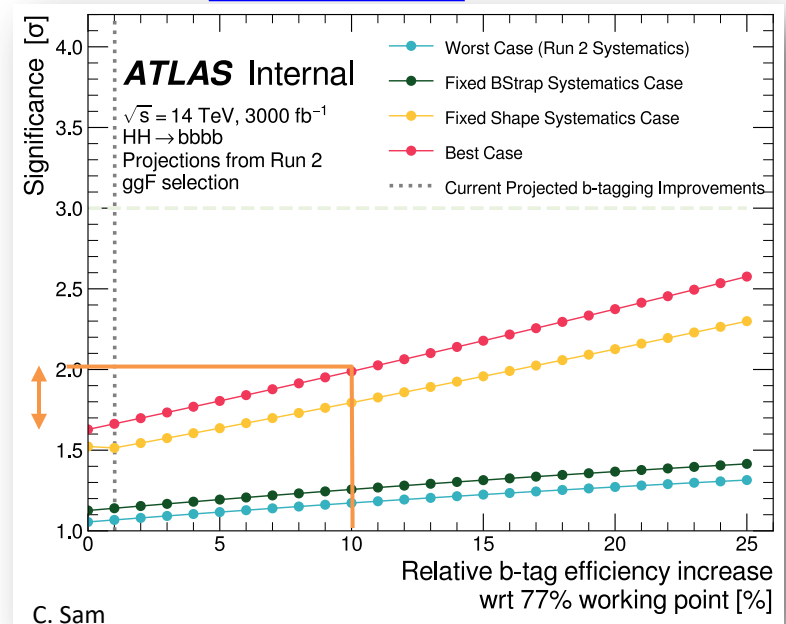
How to boost analysis sensitivity in HL-LHC?

Reduce systematics, increase signal efficiency for instance via improved object reconstruction!

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



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



- Run2-like systematics would wash out b-tagging improvements!
- But... a hypothetical **10% improvement in btag. eff.** with HL-LHC systematics would buy us **~0.3 σ**, i.e. **~ 500 fb⁻¹!!!**
- Similar consideration for $HH \rightarrow b\bar{b}b\bar{b}$ even if the leading systematics are of different nature!

B-tagging improvements would naturally propagate to most of the HH channels

How to boost analysis sensitivity in HL-LHC?

VBF H→inv extensively studied at the time of the [HGTD TDR](#), results still valid!

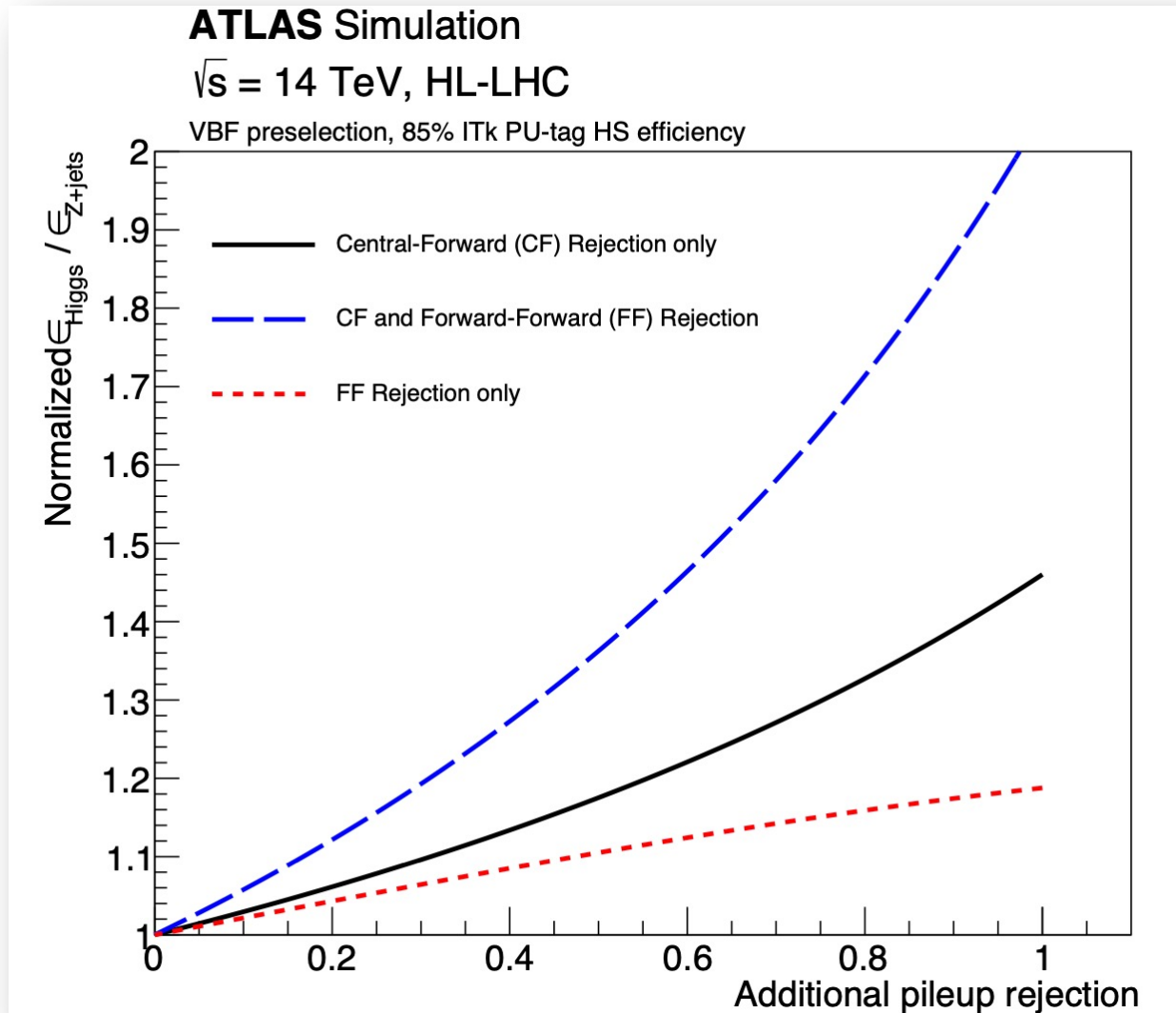


Fig. 3.25
Normalized signal over background gain relative to ITk-only pileup jet suppression performance, as a function of the additional pileup jet rejection from HGTD. The solid black (dotted red) line represents the HGTD improvement from the CF (FF) event topologies separately. The dotted blue line shows the total improvement when the combined HGTD+ITk pileup suppression algorithm is applied to all jets in the event.

Next Steps

- Now that we know more quantitatively the impact of btagging improvements in certain HH analyses, we need to quantify where the introduction of a timing layer in ATLAS takes us.
- Tools to study this are being put together and at the same time impact on other physics channels is being looked into:
 - HH->b \bar{b} tt through improvements also in tau reconstruction
 - Potentially H->cc
- Submitted a proposal for a discussion on this for the first time in ATLAS during the Upgrade Performance workshop
 - <https://indico.cern.ch/event/1098662/>

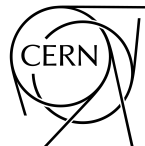


Thanks for your attention!



F. Cairo, From Conn(II)ecting the dots

Valentina Maria Martina Cairo



How to boost analysis sensitivity in HL-LHC?

VBF $H \rightarrow \text{inv}$ extensively studied at the time of the [HGTD TDR](#), results still valid!

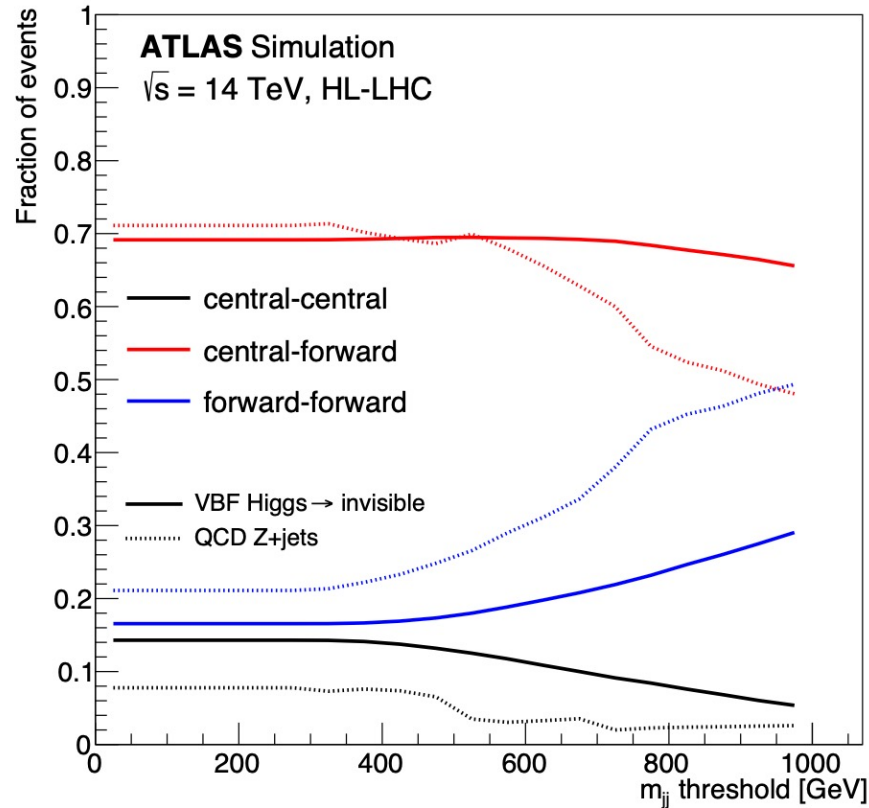
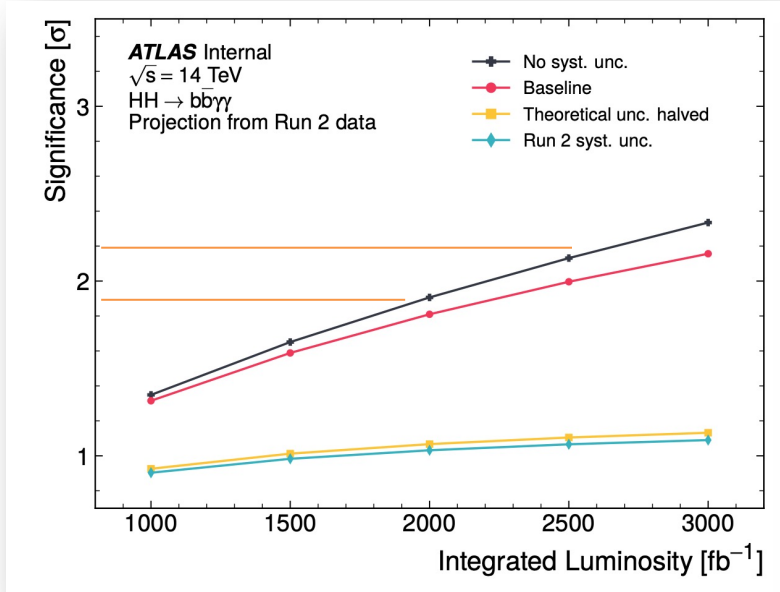


Figure 3.24: The dashed line shows the fraction of signal VBF $H \rightarrow \text{invisible}$ and Z+jet background events as a function of a m_{jj} threshold after a loose VBF preselection. Forward jets are those with $|\eta| > 2.4$. Solid (dotted) lines correspond to VBF $H \rightarrow \text{invisible}$ (Z+jet) events. The fraction of central-central, central-forward, and forward-forward events are shown in black, red, and blue colors respectively.

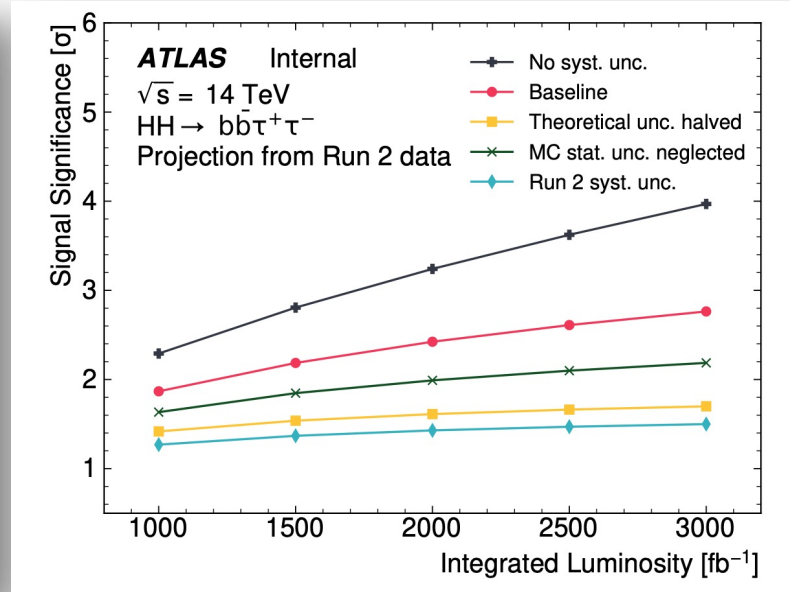
HL-LHC Extrapolations

- Various systematics scenarios studied

[ATL-COM-PHYS-2021-1020](#)



[ATL-COM-PHYS-2021-1023](#)



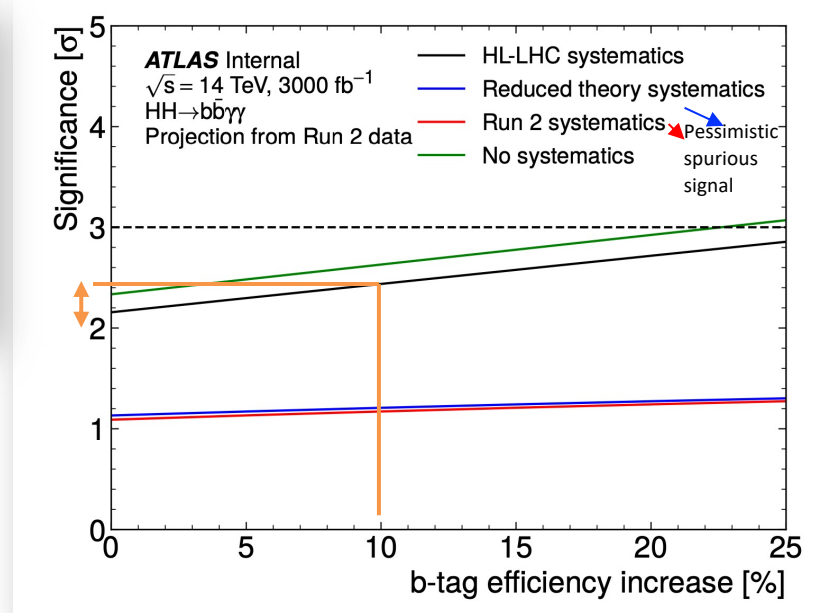
How to boost analysis sensitivity in HL-LHC?

Reduce systematics, increase signal efficiency for instance via improved object reconstruction!

- An example: the $HH \rightarrow \gamma\gamma b\bar{b}$ case

Background Modeling Uncertainty Scenario	Spurious Signal ($N \times$ Run 2 value)	95% CL Upper Limit	Significance [σ]
No syst. uncert. (optimistic)	0	0.93	2.2
	1	0.93	2.2
Improved syst. uncert. (aggressive)	2	0.94	2.1
	4	0.96	2.1
Improved syst. uncert. (conservative)	10	1.1	1.8
	20	1.5	1.3
Current Run 2 syst. uncert. (pessimistic)	25	1.7	1.1

- Systematics dominated by spurious signal!**
 - Combination of intrinsic bias due to bkg mismodeling & statistical fluctuations in bkg templates (limited MC size)
 - Strong motivation for improvements in background modelling** (Gaussian Process Regression, dedicated $\gamma\gamma+hf$ in 4FNS samples, etc)

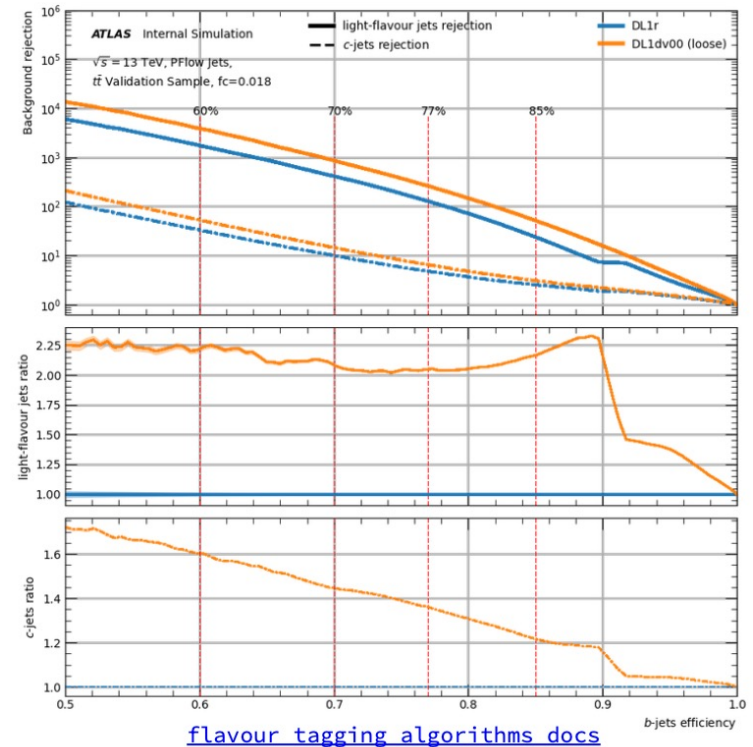


- Run2-like systematics would wash out b-tagging improvements!
- But... a hypothetical **10% improvement in btag. eff.** with HL-LHC systematics would buy us **$\sim 0.3 \sigma$** , i.e. $\sim 500 \text{ fb}^{-1}$!!!

How to boost analysis sensitivity in HL-LHC?

FLAVOUR-TAGGING

- FTAG software completed migrated into the AOD → DAOD step
- Main focus on exercising/understand the reprocessing (Tracking, Geant4 updates, etc.)
- Latest recommended alg: **DL1dv00**
 - Will serve as baseline for the Run 3 data-taking
 - Reoptimize track & vertex selection
 - Phase-out of old algorithms



[flavour tagging algorithms docs](#)

More details can be found in [Ellen's presentation](#)

8

https://docs.google.com/presentation/d/1C3AoIU6PBqbLCRM3R6xdmraBO2XmLEBIHmqy2qKKhU4/edit#slide=id.g1072e6ef93e_0_15

HL-LHC Extrapolations

<https://cds.cern.ch/record/2791485/files/ATL-COM-PHYS-2021-1020.pdf?version=10>

Table 2: Summary of HL-LHC scale factors for relevant systematic uncertainties according to the most up-to-date ATLAS conventions for HL-LHC projections [16].

Source	HL-LHC Scale Factor
Experimental Uncertainties	
Luminosity	0.6
Photon efficiency (ID, trigger, isolation efficiency)	0.8
Photon energy scale and resolution	1.0
Jet energy scale and resolution, E_T^{miss}	1.0
b -jet tagging efficiency	0.5
c -jet tagging efficiency	0.5
Light-jet tagging efficiency	1.0
Value of m_H	0.08
κ_λ reweighting	0.0
Spurious signal	0.0
Theoretical Uncertainties	0.5

HL-LHC Extrapolations

https://indico.cern.ch/event/1075421/contributions/4522372/attachments/2312869/3936469/HH_taskforce_hh4b_high_lumi_update_colm_sam_21_09_20.pdf

Four Systematic Scenarios

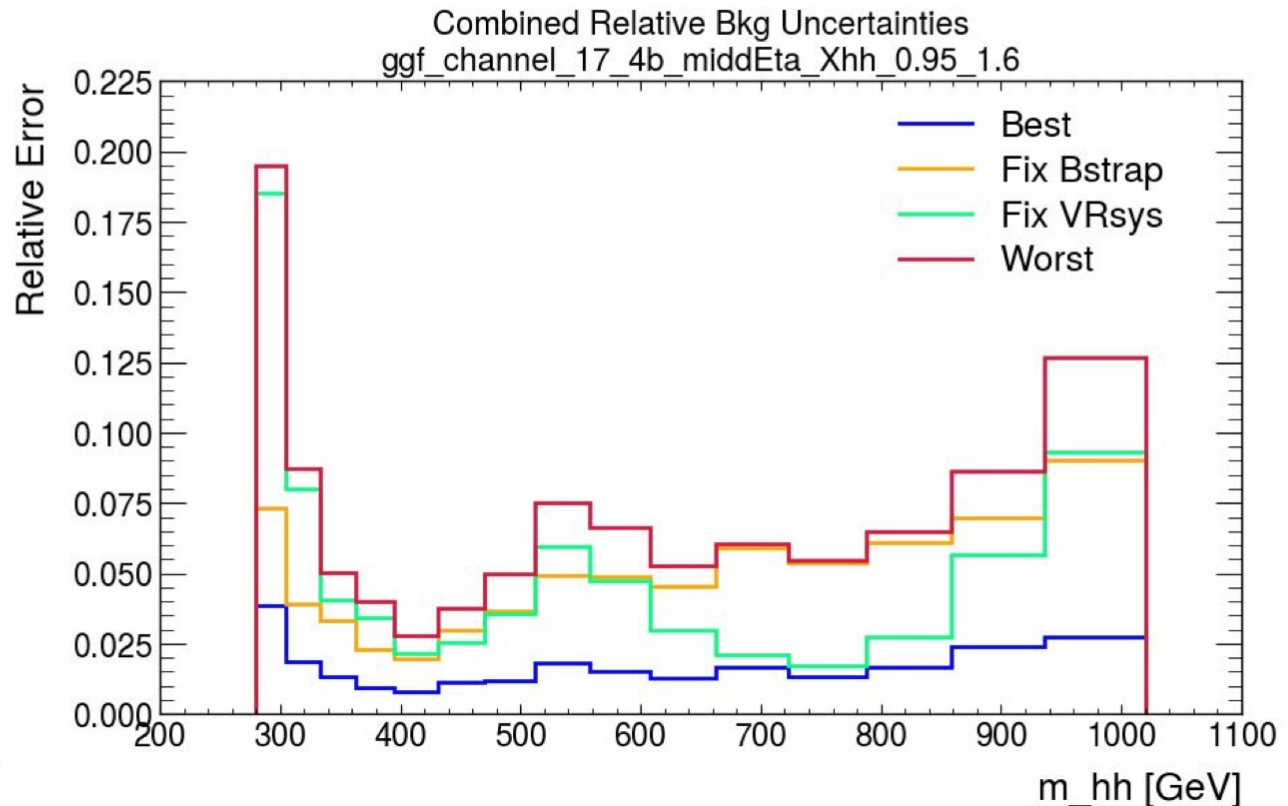
- Bkg systematics are dominant!
- But we don't know exactly how bkg systematics will change
- Propose four cases to cover the likely scenarios

Systematic	Best Case	Middle Case 1 (Fix Bootstrap)	Middle Case 2 (Fix VR Shape)	Worst Case
Stat	$\propto \mathcal{L}^{-1/2}$	$\propto \mathcal{L}^{-1/2}$	$\propto \mathcal{L}^{-1/2}$	$\propto \mathcal{L}^{-1/2}$
VR Shape	$\propto \mathcal{L}^{-1/2}$	$\propto \mathcal{L}^{-1/2}$	Fixed	Fixed
Bootstrap	$\propto \mathcal{L}^{-1/2}$	Fixed	$\propto \mathcal{L}^{-1/2}$	Fixed

HL-LHC Extrapolations

https://indico.cern.ch/event/1075421/contributions/4522372/attachments/2312869/3936469/HH_taskforce_hh4b_high_lumi_update_colm_sam_21_09_20.pdf

The Scenarios Compared ~ Combined (In quadrature) Uncertainties



*Only showing one category,
more categories in backup

HL-LHC Extrapolations

https://indico.cern.ch/event/1075421/contributions/4522372/attachments/2312869/3936469/HH_taskforce_hh4b_high_lumi_update_colm_sam_21_09_20.pdf

Results Summary

Systematics Case	Limits (95CL on μ)	Constraints on κ_λ	Constraints on κ_V^2	Signal Significance σ
Current Baseline	6.02	$-3.95 < \kappa_\lambda < 10.90$	$-0.04 < \kappa_V^2 < 2.15$	0.329
Worst	1.82	$-0.44 < \kappa_\lambda < 7.67$	$0.48 < \kappa_V^2 < 1.60$	1.083
Middle 1 (Fix Bstrap)	1.70	$-0.19 < \kappa_\lambda < 7.20$	$0.48 < \kappa_V^2 < 1.60$	1.159
Middle 2 (Fix VRsys)	1.27	$0.46 < \kappa_\lambda < 6.80$	$0.48 < \kappa_V^2 < 1.60$	1.158
Best	1.15	$0.73 < \kappa_\lambda < 6.31$	$0.65 < \kappa_V^2 < 1.59$	1.710
*Previous 2018 Study "Best Case"	~1.60	$-0.4 < \kappa_\lambda < 4.3$	N/A	1.4

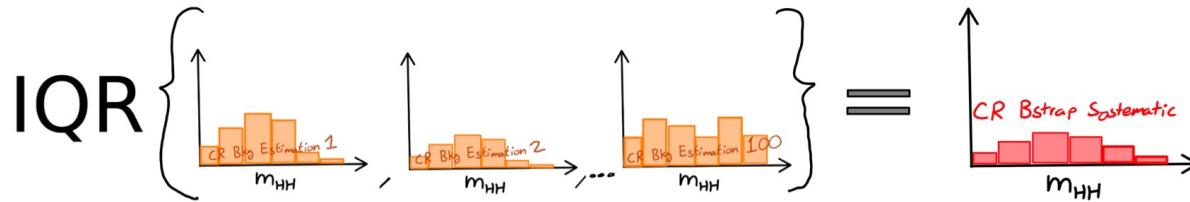
HL-LHC Extrapolations

https://indico.cern.ch/event/1075421/contributions/4522372/attachments/2312869/3936469/HH_taskforce_hh4b_high_lumi_update_colm_sam_21_09_20.pdf

The HH4b Analysis ~ The Background Systematics

1) CR Bootstrap Systematic

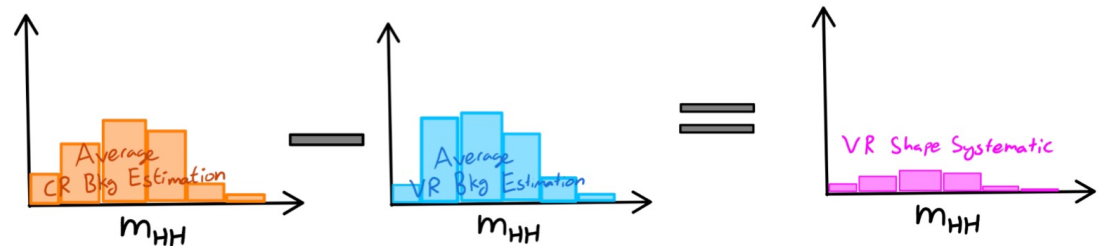
- IQR of 100 CR NNs predictions in SR



The HH4b Analysis ~ The Background Systematics

2) VR Shape Systematic

- Difference between CR and VR predictions on SR



HL-LHC Extrapolations

- Previous projections: <https://cds.cern.ch/record/2652727/files/ATL-PHYS-PUB-2018-053.pdf?version=1>

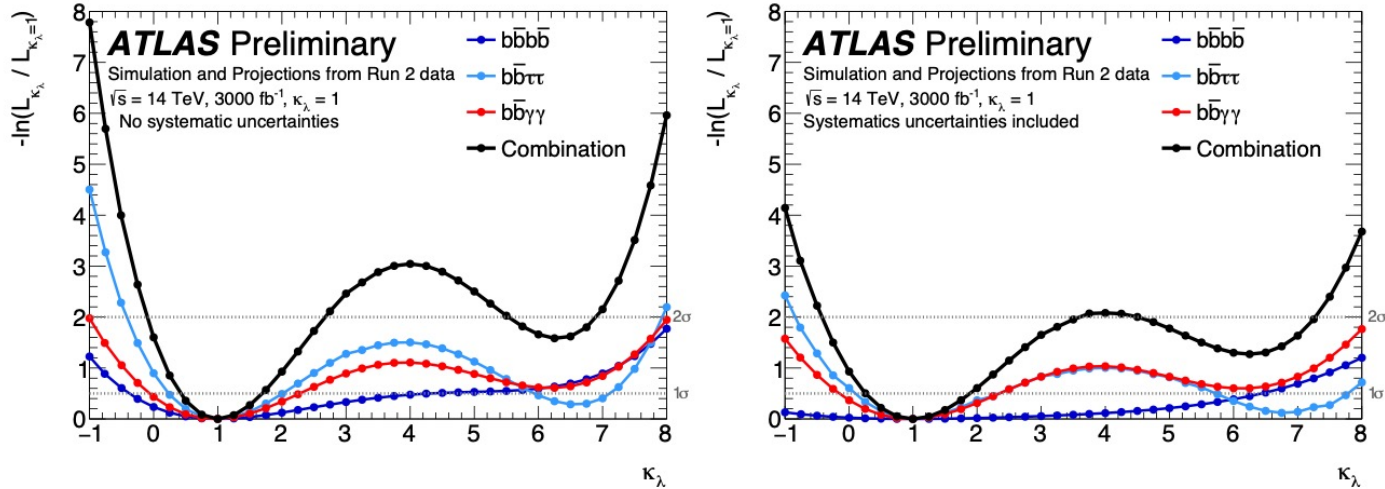


Figure 23: Negative natural logarithm of the ratio of the maximum likelihood for κ_λ to the maximum likelihood for $\kappa_\lambda = 1$ for (left) the fits with only statistical uncertainties and (right) the fits with all systematic uncertainties as nuisance parameters. The black circles show the results for the combination, while the coloured markers show the values coming from the individual channels. The dashed lines at $-\ln(L_{\kappa_\lambda}/L_{\kappa_\lambda=1}) = 0.5$ and 2.0 indicate the values corresponding to the 1σ and 2σ confidence intervals, respectively (assuming an asymptotic χ^2 distribution of the test statistic).

Scenario	1σ CI	2σ CI
Statistical uncertainties only	$0.4 \leq \kappa_\lambda \leq 1.7$	$-0.10 \leq \kappa_\lambda \leq 2.7 \cup 5.5 \leq \kappa_\lambda \leq 6.9$
Systematic uncertainties	$0.25 \leq \kappa_\lambda \leq 1.9$	$-0.4 \leq \kappa_\lambda \leq 7.3$

Table 17: Constraints on κ_λ from the likelihood ratio test performed on the Asimov dataset created from the backgrounds and the SM HH signal. Results are presented as 1σ and 2σ CI on κ_λ .

HL-LHC Extrapolations

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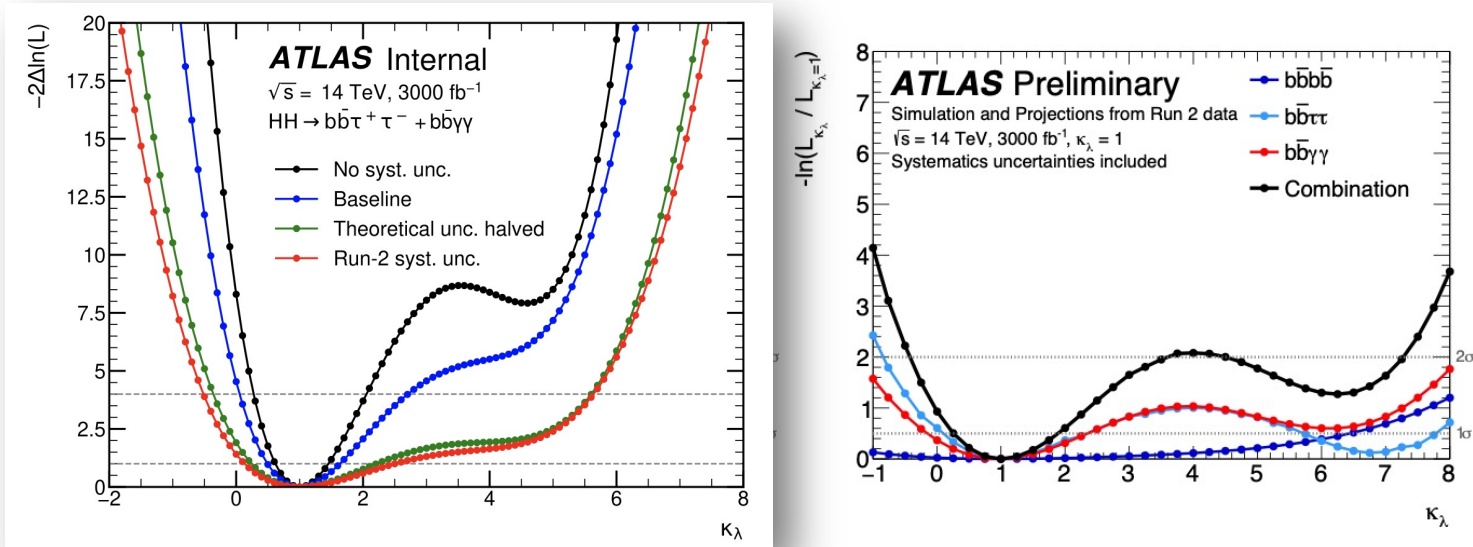


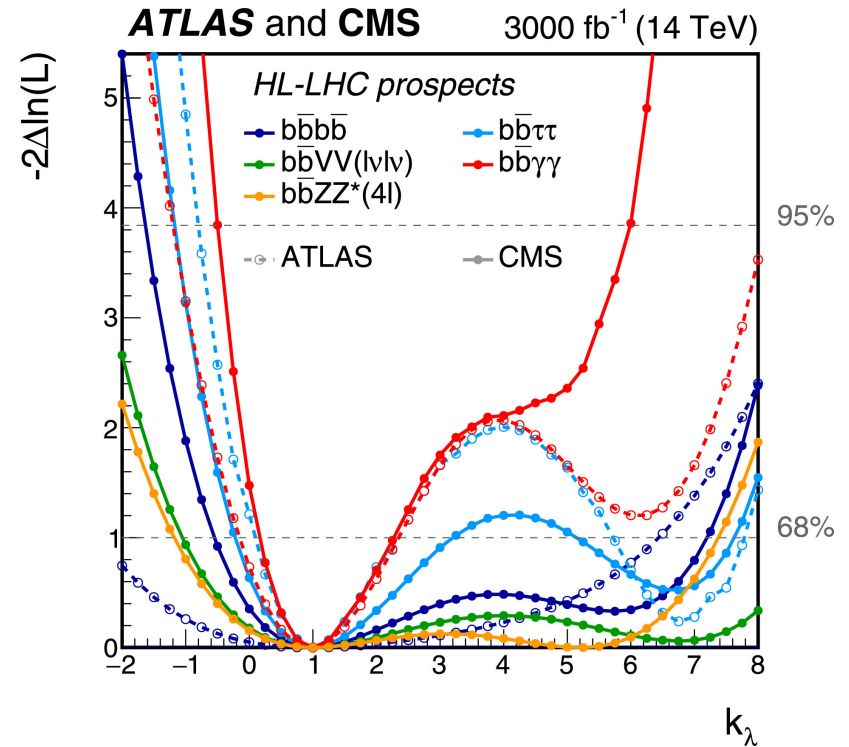
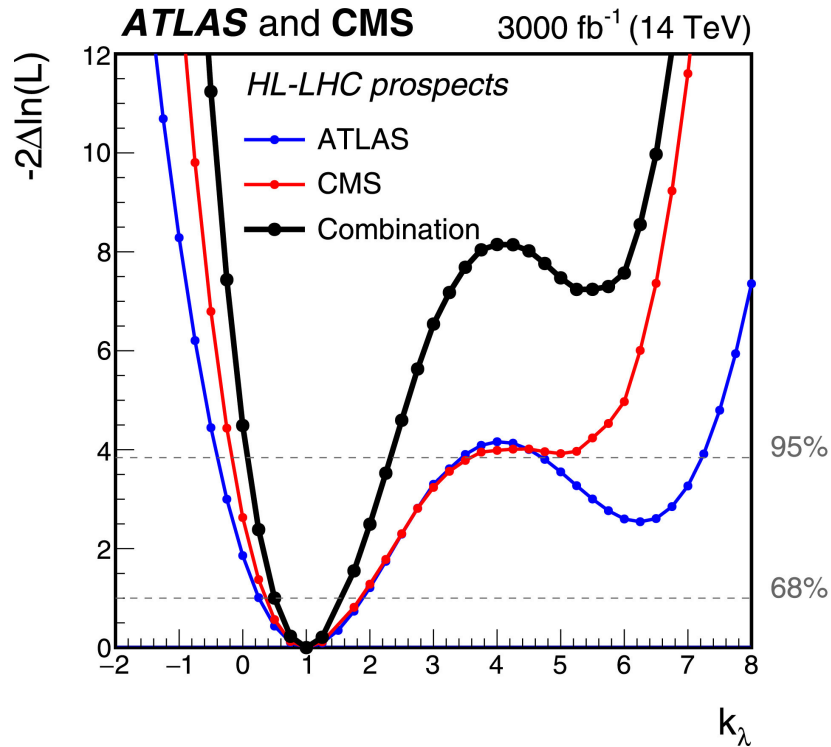
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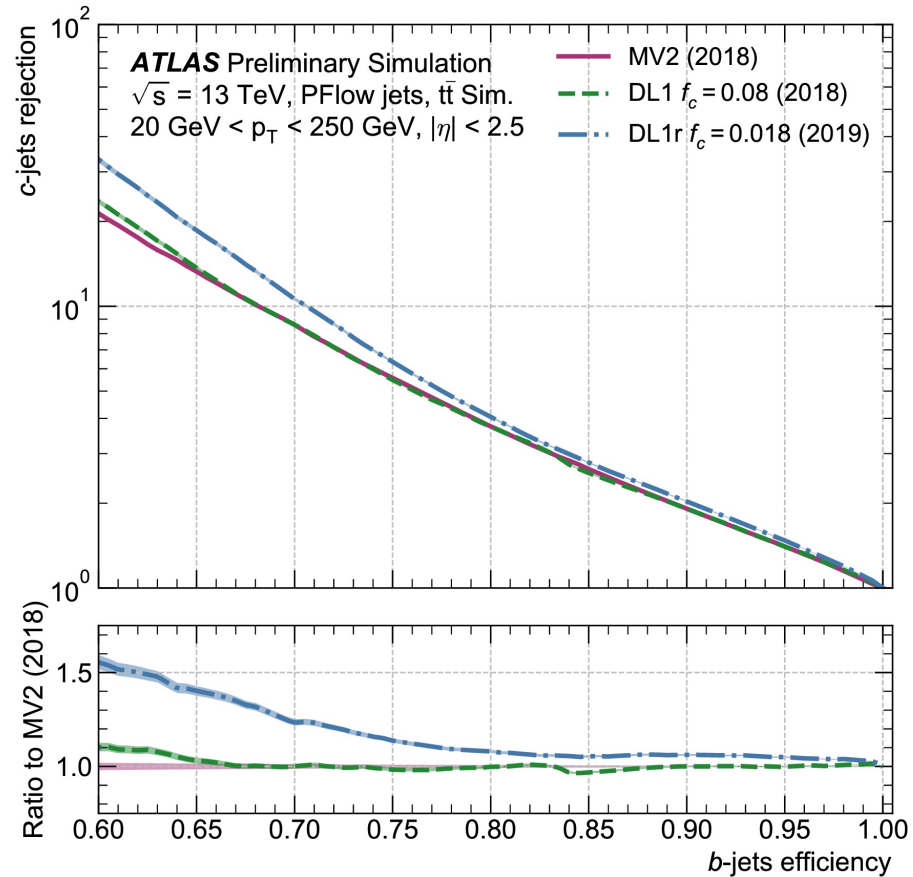
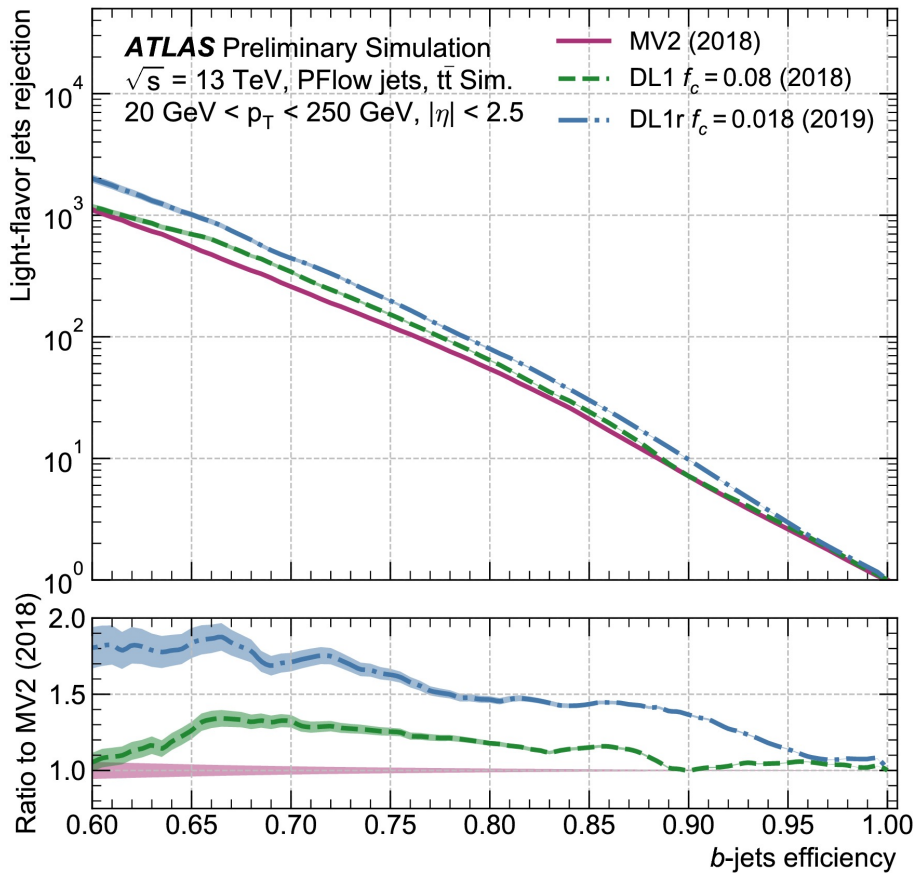
Old ATLAS-CMS Combination

<https://www.sciencedirect.com/science/article/pii/S2405428320300083?via%3Dihub>



FTag

<http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/FTAG-2019-005/>



Summary of Tau updates

- 1) Track classification (counting tracks to decide if the tau is 1P or 3P): we moved from a cut-based approach to a set of BDTs
- 2) tau ID: move from BDT to RNN documented in a PUB note
<https://cds.cern.ch/record/2688062/files/ATL-PHYS-PUB-2019-033.pdf?version=1>
- 3) Tau Energy Scale: an estimate of the TES based on tau substructure information and calo fed into a BRT was developed and used by some analyses in R20.7 but R21 brought it by default across ATLAS. This was documented in <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-029/>.

All nicely described also here:

https://indico.cern.ch/event/636010/contributions/2673165/attachments/1547582/429461/reco_id_ml_tauws.pdf

WP	Eff. 1P / 3P
Very Loose	95% / 95%
Loose	85% / 75%
Medium	75% / 60%
Tight	60% / 45%

Tau ID

<https://cds.cern.ch/record/2688062/files/ATL-PHYS-PUB-2019-033.pdf?version=1>

