LHC Measurements and HL-LHC Prospects
– selected topics

on behalf of the ATLAS and CMS collaborations

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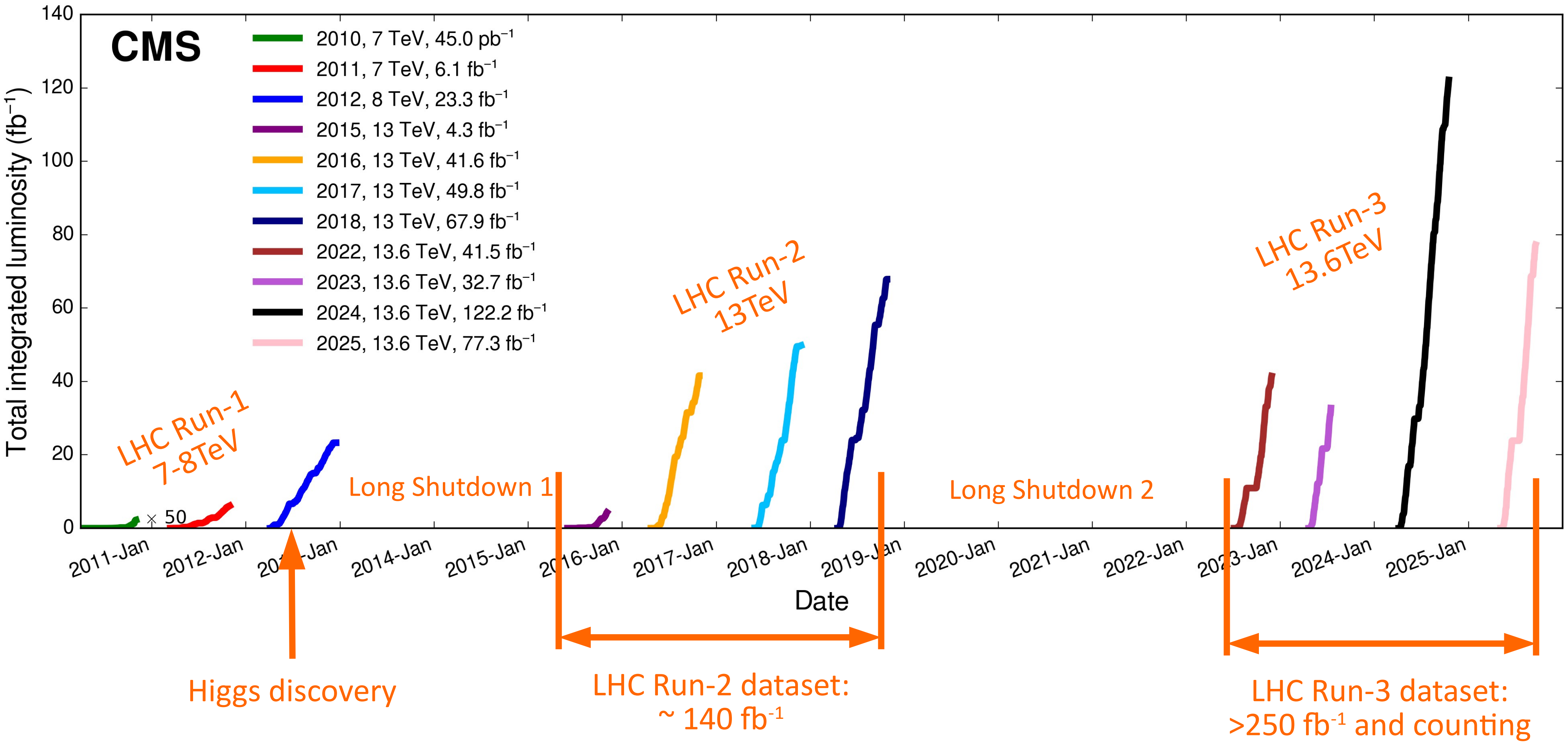
23 September 2025
DESY Theory Workshop

The LHC dataset



On the menu

Selected LHC results

- W mass
- toponium
- rare Higgs decays: $Z\gamma$, $\mu^+\mu^-$, $c\bar{c}$
- Higgs global fit
- self-coupling: H, HH and HHH
- vector boson scattering

HL-LHC prospects

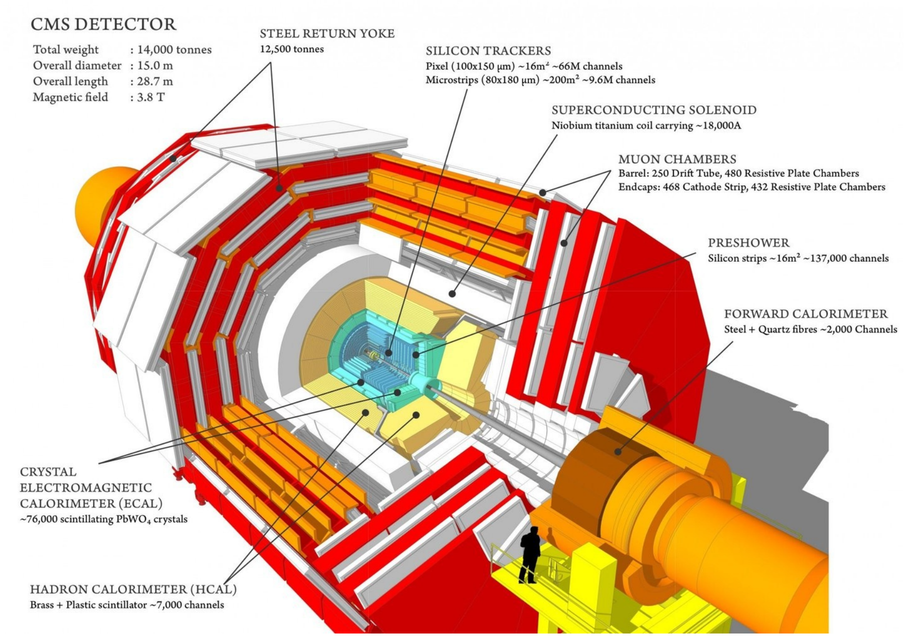
- luminosity, and more
- rare Higgs processes
- H and HH combinations
- top mass
- rare processes

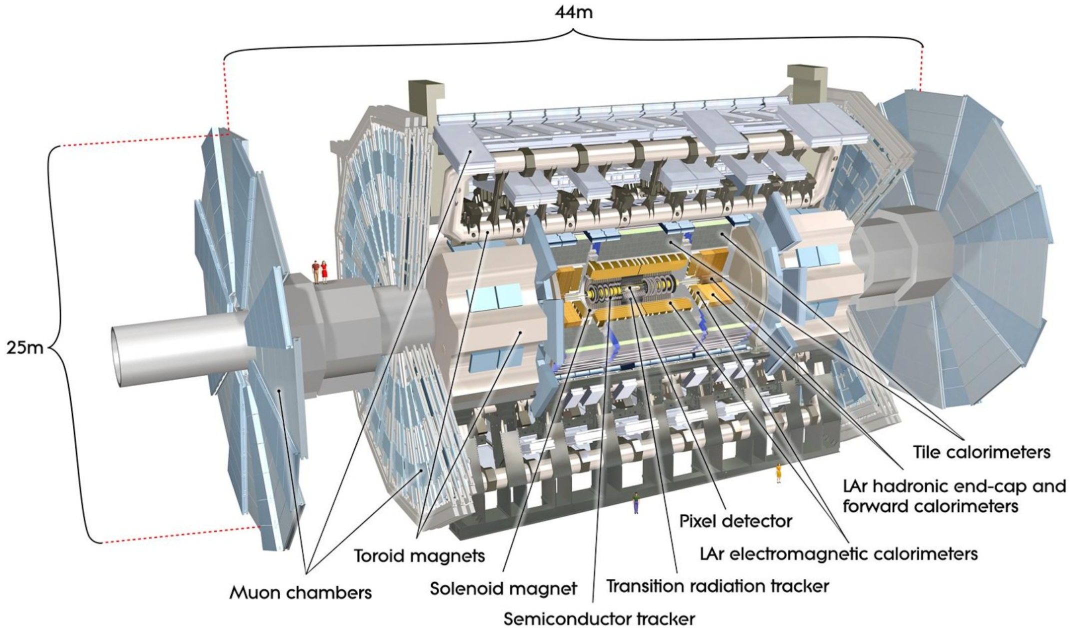
personal selection,
concentrated on:

- measurements
- recent results
- link to HL-LHC

The ATLAS and CMS detectors

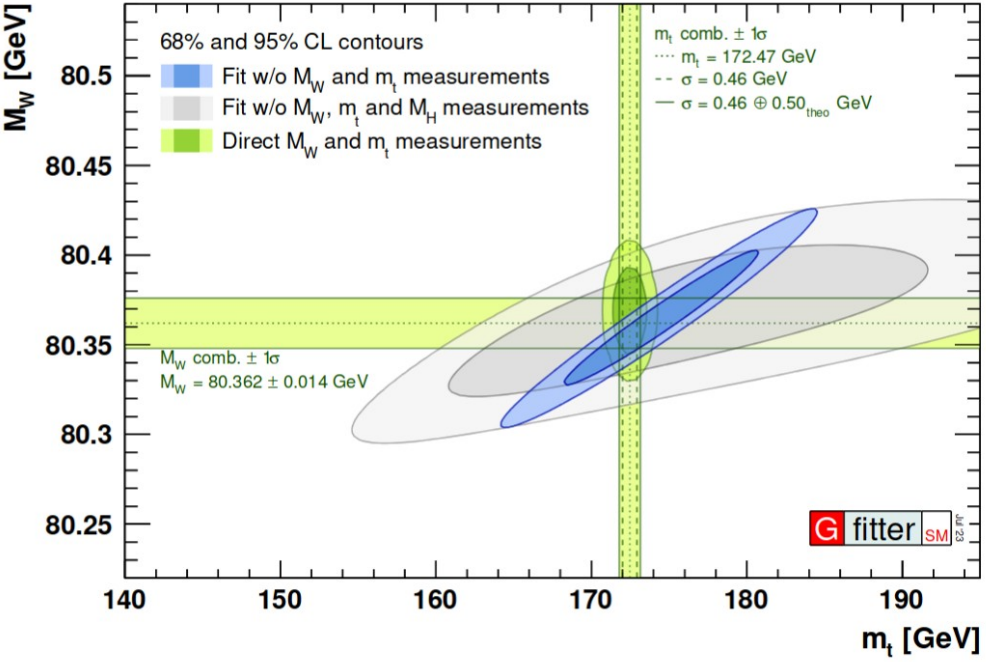
- versatile and complementary
- excellent operation since 15 years





Where do we stand?

- the Standard Model seems internally consistent
- but, we all know the shortcomings
  - so, will something break under precision tests?



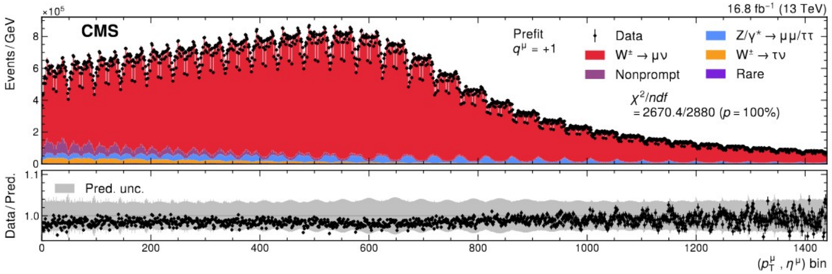
W mass in W → μν

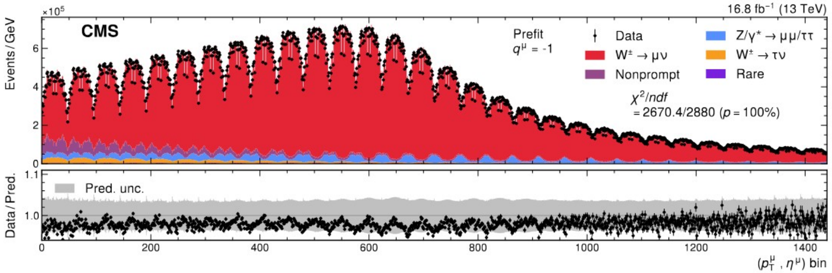
arXiv:2412.13872

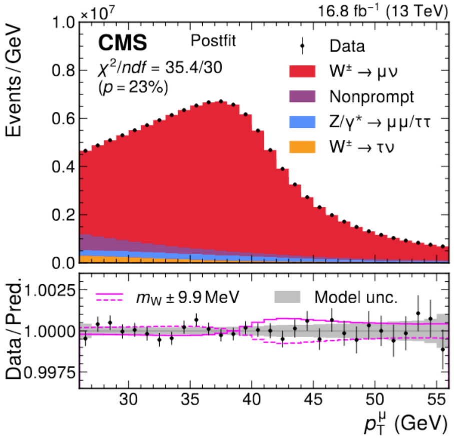
- direct W mass measurement very important test for consistency of EW data
- CMS realized the most precise measurement to date
  - using 117M W → μν candidates in 2016 data
    - <pileup> = 25
  - highly granular in eta, pT, Q: ~ 3000 bins
  - complex fit with ~4000 nuisance parameters

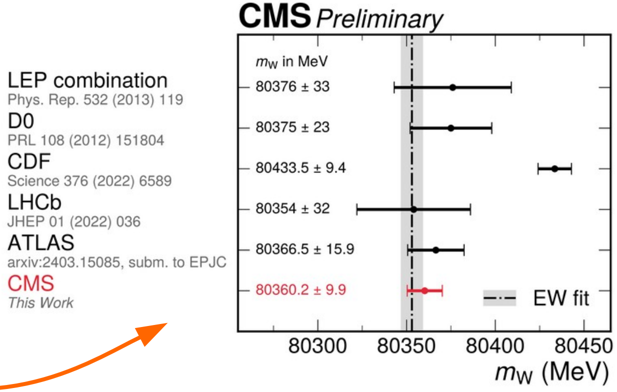
$$m_W = 80\,360.2 \pm 2.4\,(\text{stat}) \pm 9.6\,(\text{syst}) = 80\,360.2 \pm 9.9\,\text{MeV}$$

  - largest source of uncertainties from muon p_T scale and pdf's
  - muon p_T scale calibrated on J/ψ, validated on Υ(1s) and Z









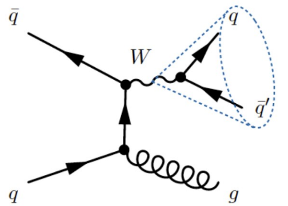
Jet mass distributions and W mass

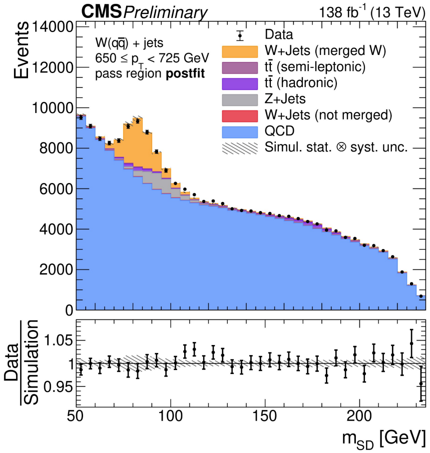
New

CMS-PAS-SMP-24-012

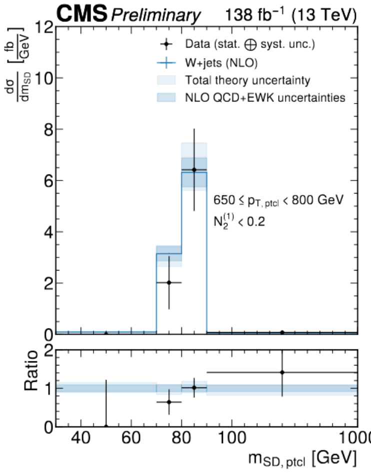
- cross section measurement of W(qq)+jets
  - at high momentum $p_T > 650$ GeV
  - double-differential in jet p_T and jet mass
- W(qq) object from wide jet
  - substructure tagged for 2-prong with ParticleNet algo → suppresses QCD background
  - mass from jet groomed with softdrop algorithm → suppresses soft and wide-angle emission
- unfolding to both particle-level jet p_T and mass
  - sensitive to the W mass → turn into measurement
- first measurement at a hadron collider of the W mass in the all-jets final state

  m(W) = 80.77 ± 0.57 GeV

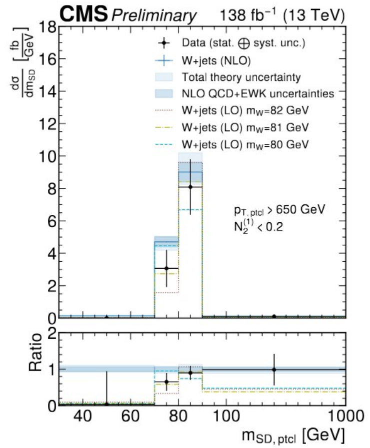




unfold



measure m_W



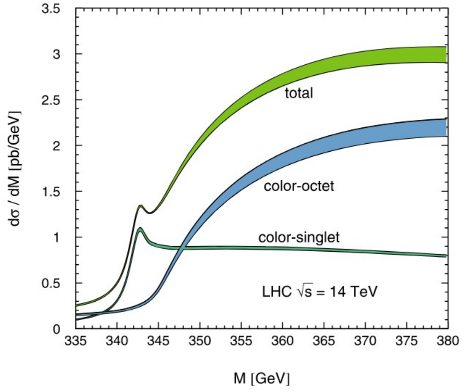
Toponium (?)

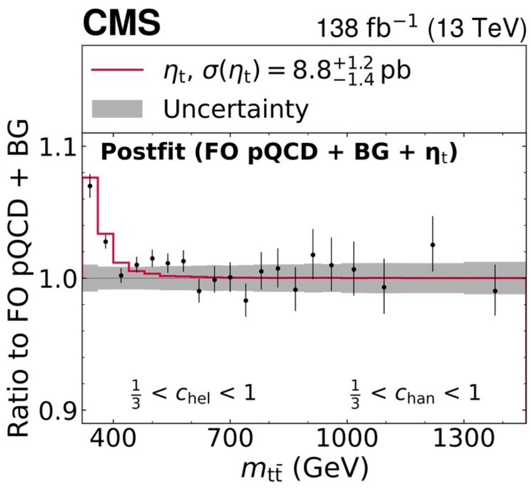
Rep. Prog. Phys, 88 (2025) 087801

Observation of a pseudoscalar excess at the top quark pair threshold

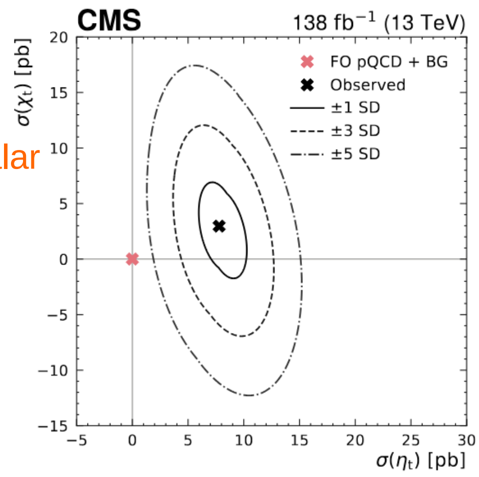
- NR-QCD predicts color-singlet pseudoscalar quasi-bound toponium state
  - just below the ttbar threshold
  - experimentally challenging: 1% of cross section, in very narrow m(tt) window
- searched for in dilepton final state
  - using m(tt) and angular variables probing spin correlations

EPJC 60 (2009) 375





scalar



pseudoscalar

$$\sigma(\eta_t) = 8.8 \pm 0.5\,(\text{stat})\,^{+1.1}_{-1.3}\,(\text{syst})\,\text{pb} = 8.8\,^{+1.2}_{-1.4}\,\text{pb}$$

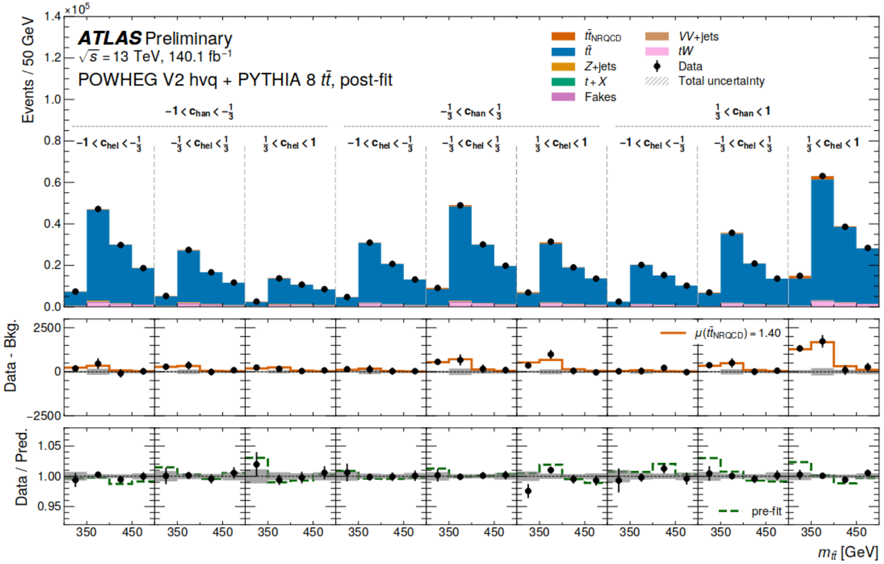
Toponium (?)

ATLAS-CONF-2025-008

New

Observation of ttbar cross-section enhancement at threshold

- dilepton events, similar angular and mass binning
- testing also more realistic toponium model (Eur. Phys. J. C 85 (2025) 157)

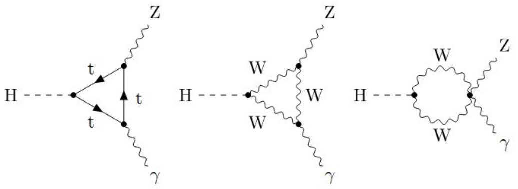


- background-only hypothesis rejected at 7.7 sigma

$$\sigma(t\bar{t}_{\text{NRQCD}}) = 9.0 \pm 1.2\ (\text{stat.}) \pm 0.6\ (\text{syst.})\ \text{pb}$$

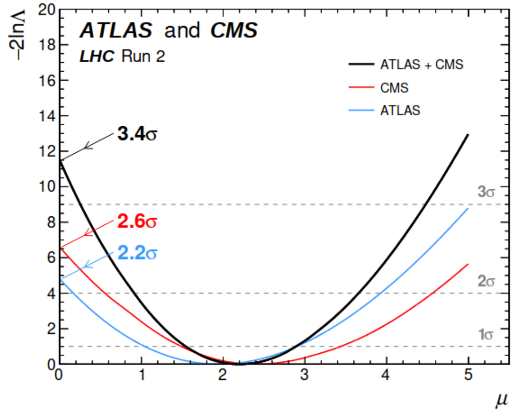
- experimental picture is unambiguous: both experiments observe the effect
  - now more detailed characterization
- theoretical interpretation to be clarified
  - NLO EW and NNLO QCD corrections, off-shell effects in decay,… is it really toponium?

$H \to Z(\ell^+\ell^-)\,\gamma$



- Loop-suppressed decay in the SM
  - sensitive to BSM effects
  - BR($H \to Z\gamma$) ~ 1.5 10^{-3}
- previous Run-2 ATLAS+CMS combination (PRL 132 (2024) 2, 021803)
  - 3.4 sigma evidence
  - 1.9 sigma agreement with SM

    $\mu = 2.2 \pm 0.6\,(\text{stat.})^{+0.3}_{-0.2}\,(\text{syst.})$

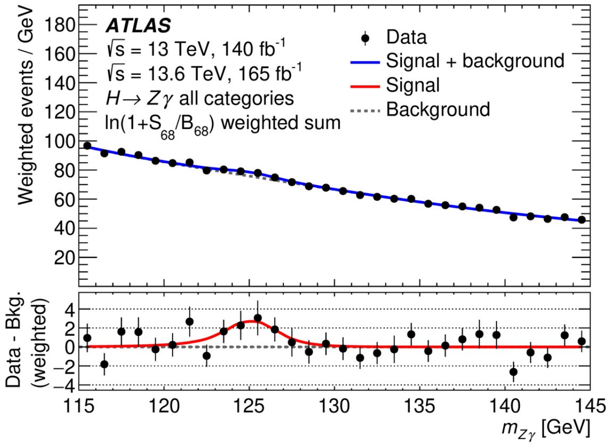


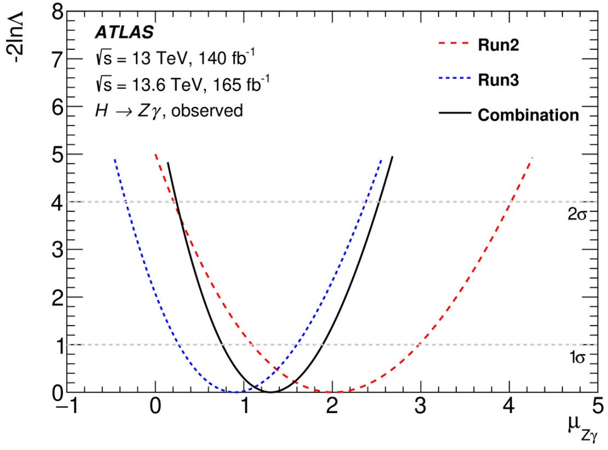
arXiv:2507.12598

- New from ATLAS
  - Run-2+Run-3 ~ 300fb^{-1}
  - previous excess diluted

New

- note: different analysis selections can hide unexpected source of excess
  - much tighter Z window cut in Run-3
  - see eg. JHEP 06 (2025) 043





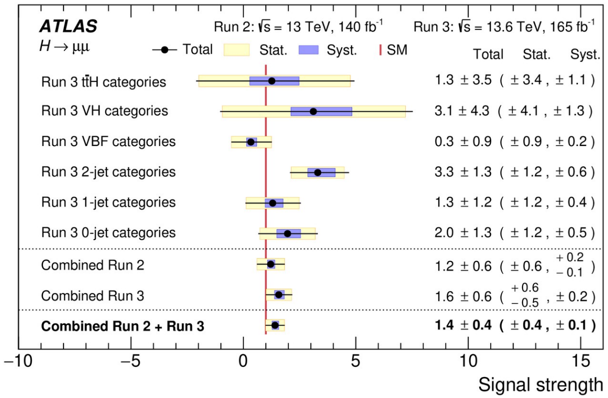
H → $\mu^+\mu^-$

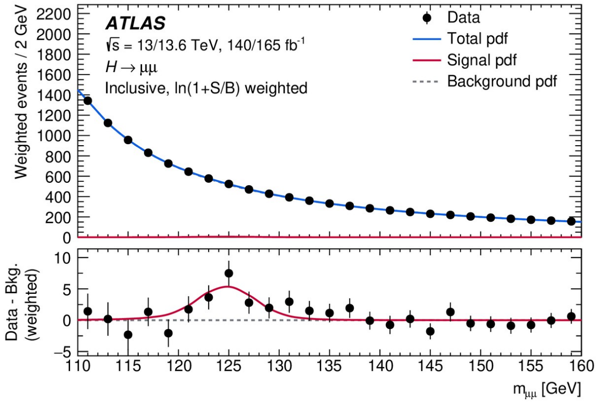
New

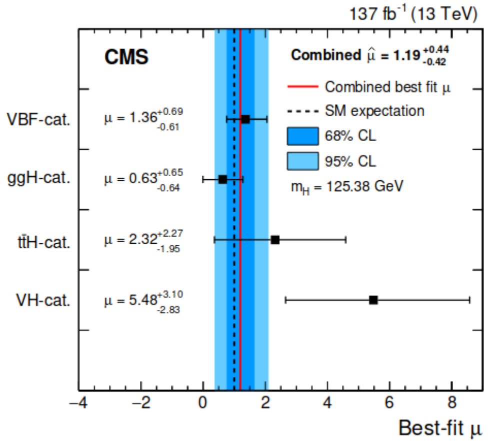
arXiv:2507.03595

- test of the 2nd generation Yukawa sector
  - rare decay with huge DY background
    - BR (H → $\mu^+\mu^-$) = 2.2 10^{-4}
  - inclusive S/B ~ 0.2%
  - optimize in event categories
- ATLAS: Run-2 + Run-3 ~ 300 fb^{-1}
  - ~50% sensitivity improvement over Run-2 only
- evidence for H → $\mu^+\mu^-$
  - significance 3.4 σ (2.5 σ exp.)
  - σ/σ_{SM} = 1.4 ± 0.4
    - in agreement with SM prediction
- status CMS from Run-2
  - evidence at 3.0 sigma level (2.5 σ exp.)
  - $\sigma/\sigma_{SM} = 1.19\ ^{+0.40}_{-0.39}\ (stat)\ ^{+0.15}_{-0.14}\ (syst)$

JHEP 01 (2021) 148







$H \to c\bar{c}$

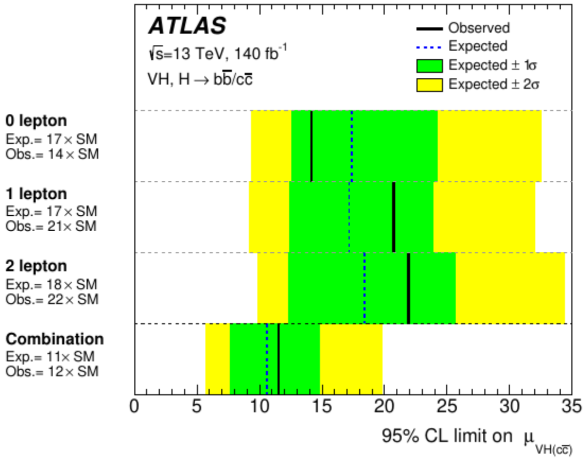
- joint ATLAS measurement of $H \to b\bar{b}$ and $H \to c\bar{c}$ in VH production
  - complex categorization
- WH($b\bar{b}$) and ZH($b\bar{b}$) SM-like, each at ~5σ level
- σ (VH, $H \to c\bar{c}$) < 11.5 σ_{SM} @ 95% CL (exp. 10.6 σ_{SM})
- $|\kappa_c|$ < 4.2 @ 95% CL

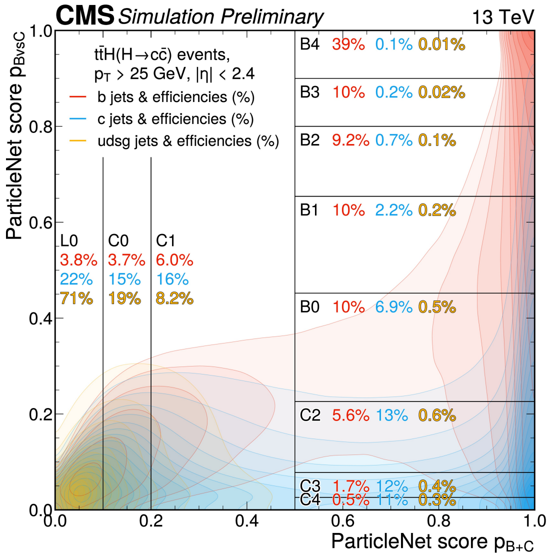
JHEP 04 (2025) 075

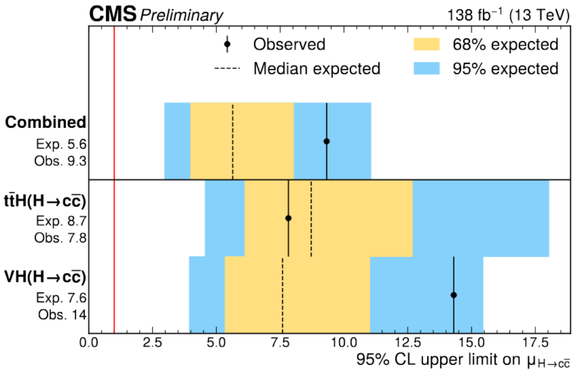
- CMS also added $H \to b\bar{b}$ and $H \to c\bar{c}$ in ttH production
  - 2D categorization of simultaneous b- and c-flavour tagging outputs
- ttH($b\bar{b}$) compatible with SM, 4.4σ evidence
- σ (ttH, $H \to c\bar{c}$) < 7.8 σ_{SM} @ 95% CL (exp. 8.7 σ_{SM})
- $|\kappa_c|$ < 3.0 @ 95% CL

New

CMS-PAS-HIG-24-018







Higgs global picture: production and decay

- global combinations are Herculean efforts
  - many many measurements, mostly coming out of phase
  - with overlaps and (time-dependent) assumptions
  - strong emphasis cross-experiment on harmonizing simulation, interpretation,…

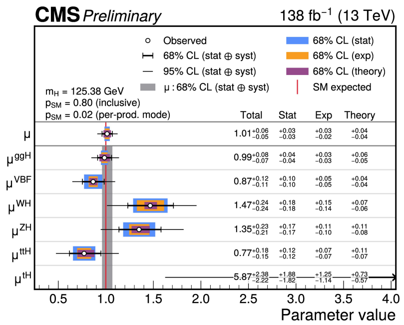
- latest global interpretation from ATLAS (up to Run-2)
  - including some latest results like VH(cc)
  - overall signal strength: σ/σ_{SM} = 1.023 $^{+0.056}_{-0.053}$
    - uncertainty theory dominated!
  - all main production modes firmly established
    - and SM-like
    - stat ~ syst ~ 5%
  - more and more precision on both boson and fermion final states

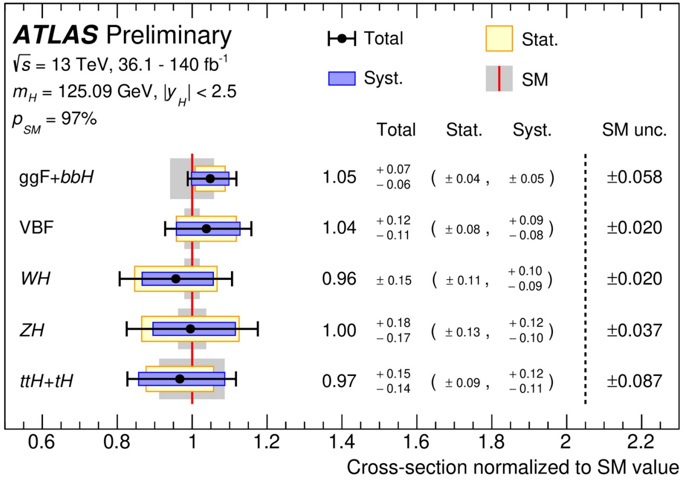
New

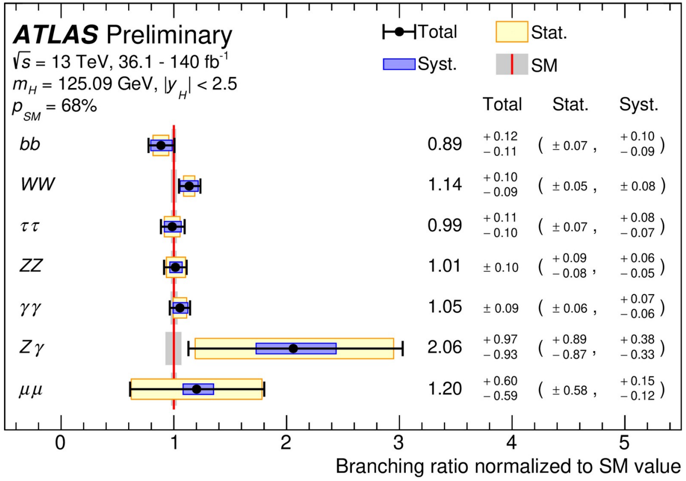
ATLAS-CONF-2025-006

- corresponding CMS results
  - σ/σ_{SM} = 1.014 $^{+0.055}_{-0.053}$

CMS-PAS-HIG-21-018







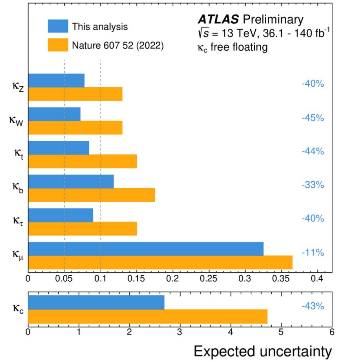
Higgs global picture: couplings

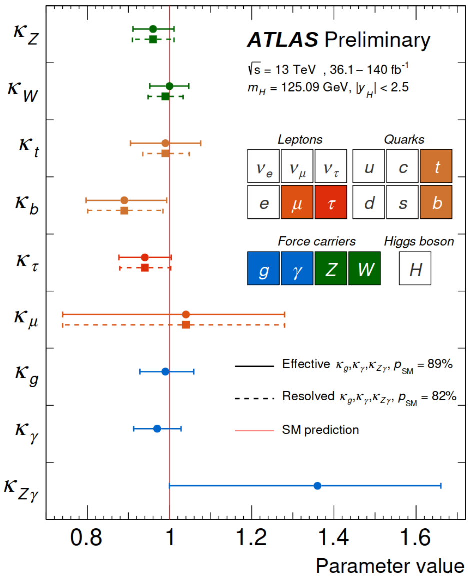
- interpretation in the kappa framework
  - coupling modifiers kappa: couplings normalized to SM:

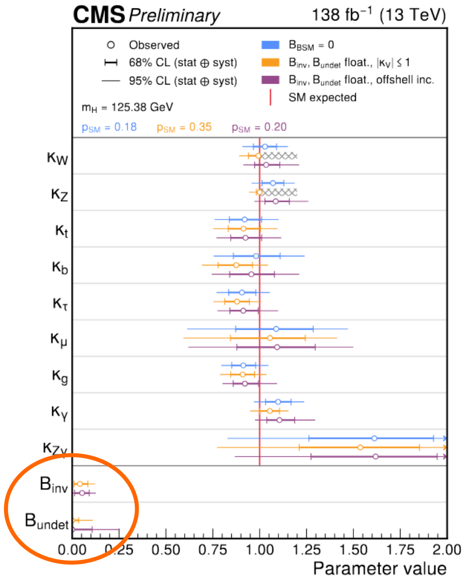
$$\sigma_i \times \mathrm{B}(H \to f) = \frac{\sigma_i \times \Gamma_f}{\Gamma_H} = \frac{\kappa_i^2 \kappa_f^2}{\kappa_H^2} \sigma_i^{\mathrm{SM}} \times \mathrm{B}^{\mathrm{SM}}(H \to f)$$

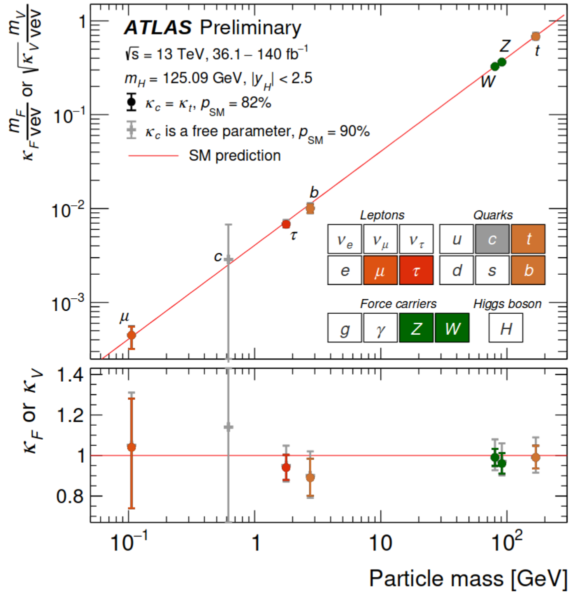
  - achieved precision
    - 5-10% for W/Z
    - 10-20% for 3rd gen

κ_c knowledge directly impacts other coupling uncertainties via Higgs width



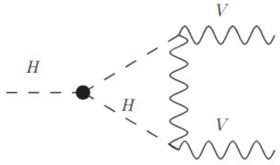


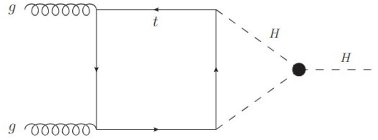




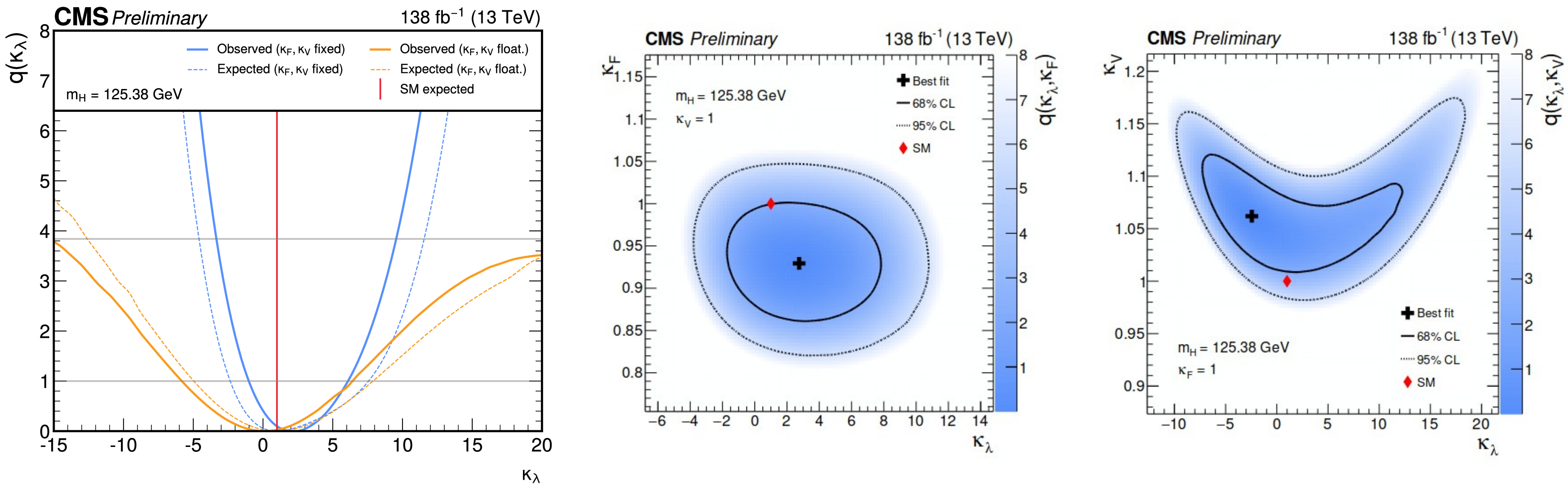
Higgs self-coupling: from H measurements

CMS-PAS-HIG-21-018

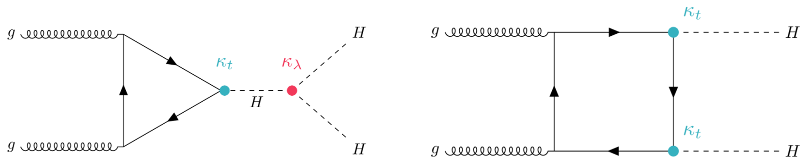




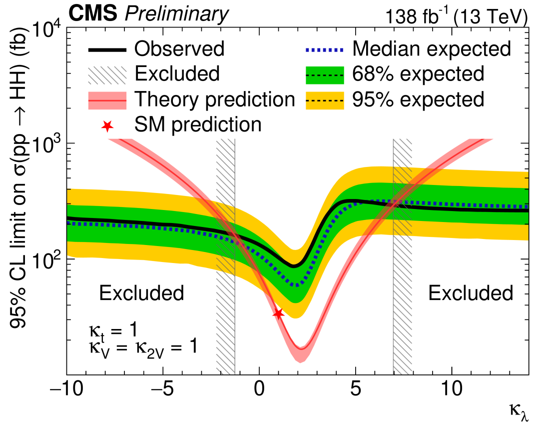
- triple-Higgs coupling λ affects single-Higgs measurements through EW NLO corrections
  - both in production and decay
- best fit $\lambda = 2.1^{+4.0}_{-3.2}$
  - assuming $\kappa_f = \kappa_V = 1$
  - similar sensitivity to direct HH searches!



Higgs self-coupling: hunting HH



- full Run-2 combinations from ATLAS and CMS
  - σ (HH) < 2.9 σ_{SM} @ 95% CL (exp. 2.4 σ_{SM}) [ATLAS]
    σ (HH) < 3.5 σ_{SM} @ 95% CL (exp. 2.5 σ_{SM}) [CMS]
  - $-1.2 < \kappa_\lambda < 7.2$ [ATLAS] / $-1.39 < \kappa_\lambda < 7.02$ [CMS] @ 95% CL
  - sensitivity dominantly from bbττ, bbγγ, bbbb
    - important role for flavour tagging and triggering
  - similar combined performance, but individual channel differences
    - room for improvement!



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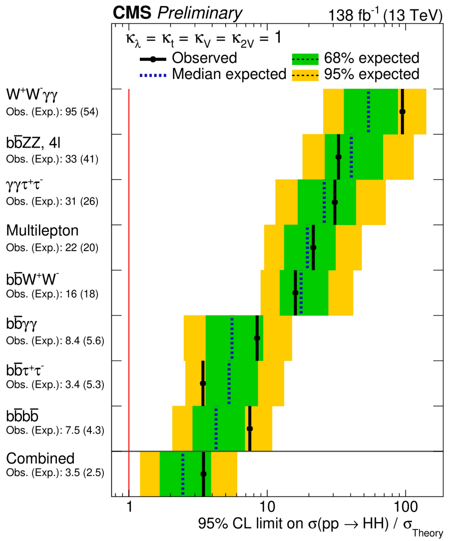
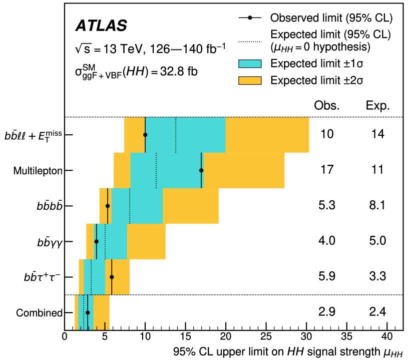
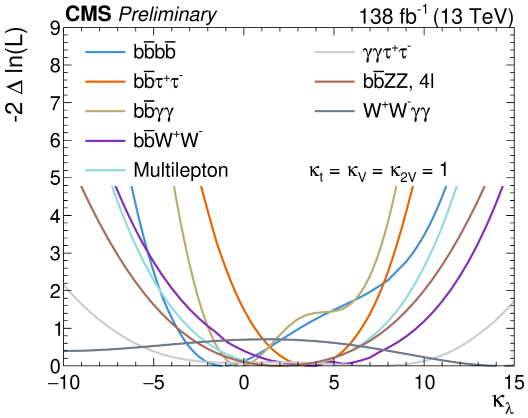
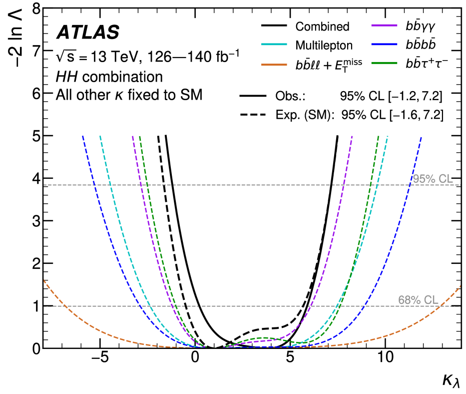


PRL 133 (2024) 101801



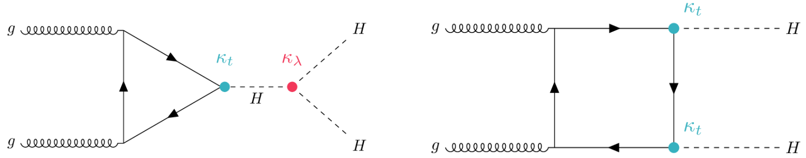




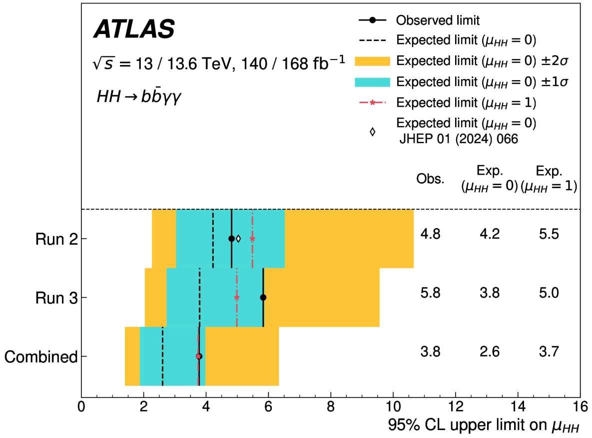
Higgs self-coupling: hunting HH

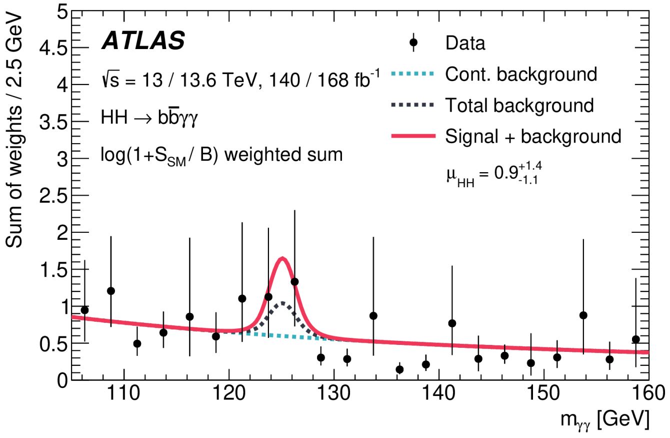
arXiv:2507.03495

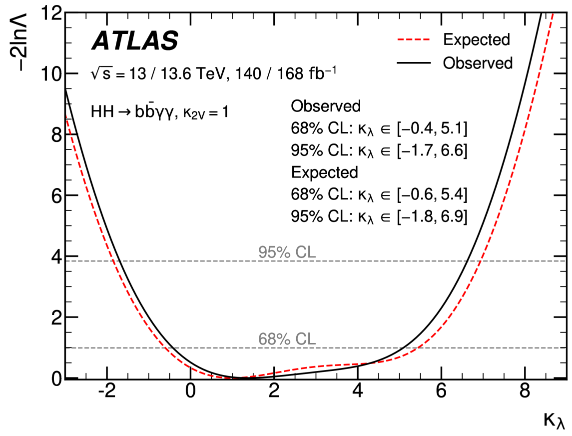
New



- ATLAS: first results with Run-2 + partial Run-3 data
  - in the very sensitive HH → bbγγ channel
  - 140 fb^{-1} @ 13TeV + 168 fb^{-1} @ 13.6TeV
  - improvements: new flavour tagger, reoptimization, m(bb) fit
  - $\sigma(HH) / \sigma_{SM} = 0.9^{+1.4}_{-1.1}$
    - significance 0.9 sigma (1.0 sigma expected)
    - similar sensitivity as Run-2 legacy analysis (5 channels)



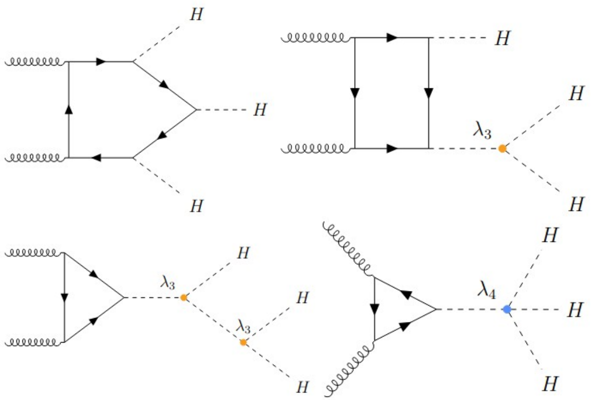




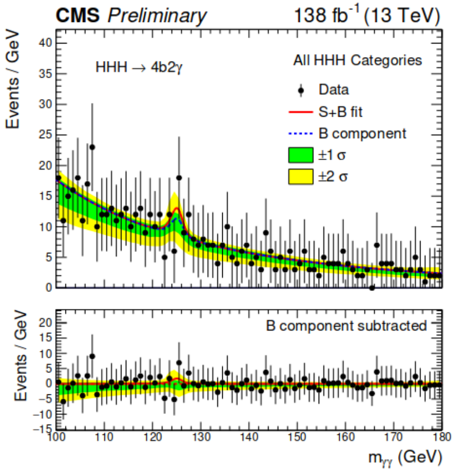
Higgs self-coupling: search for HHH

CMS-PAS-HIG-24-015

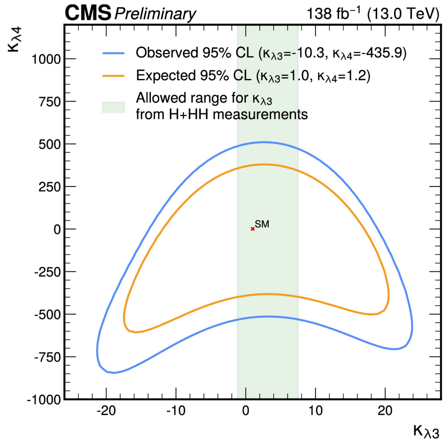
New



- HHH → 2γ 4b channel, σ(SM) = 0.079 fb + combined BR = 0.2%
  - sensitivity to both λ_3 and λ_4
- ML training against resonant (H)H → γγ and non-res. backgrounds
- signal extracted with fit on m(γγ) spectrum
  - in background-dependent categories



σ < 244 fb at 95% CL (< 152 fb exp.)

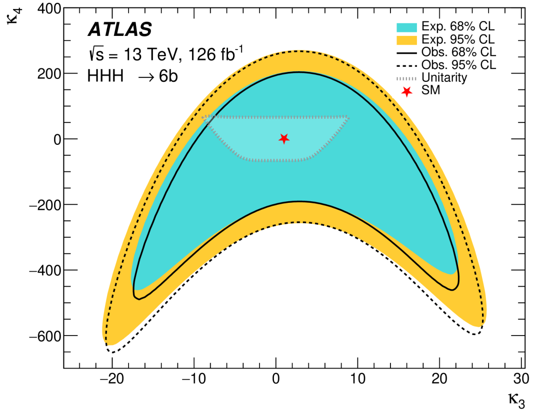


$-16.1\ (-13.8) < \kappa(\lambda_3) < 20.2\ (18.0)$ [for $\kappa(\lambda_4) = 1$]

$-533\ (-379) < \kappa(\lambda_4) < 541\ (406)$ [for $\kappa(\lambda_3) = 1$]

Previous ATLAS search in HHH → 6b channel

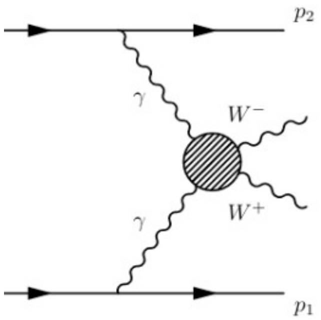
PRD 111 (2025) 032006



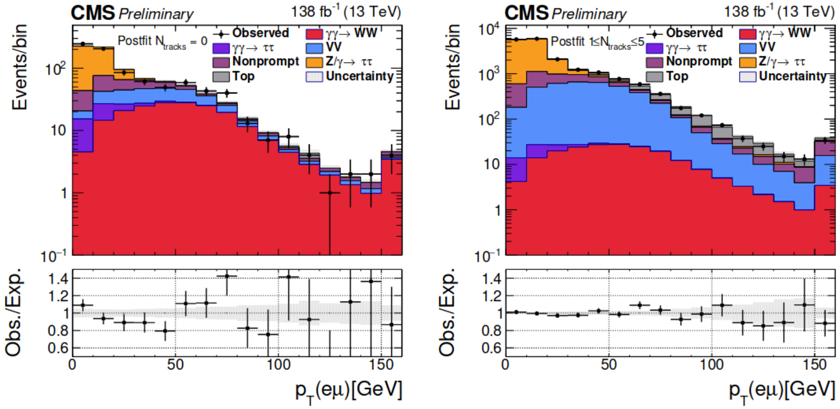
Measurement of $\gamma\gamma \rightarrow W^+W^-$

New

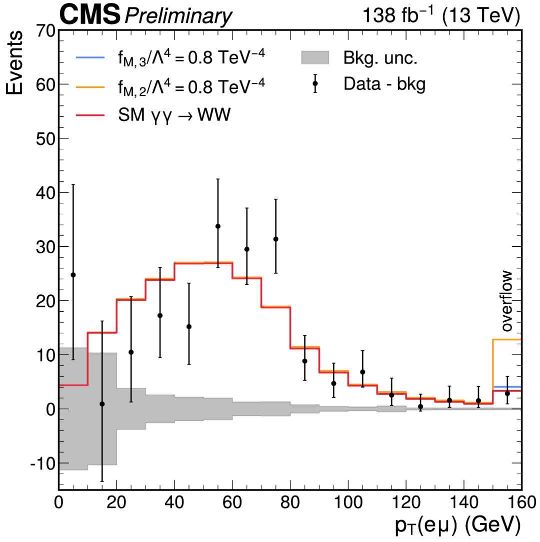
CMS-PAS-SMP-24-019



- vector boson scattering prime target for high luminosities
- latest new analysis: $\gamma\gamma \rightarrow W^+W^- \rightarrow e\,\nu_e\,\mu\,\nu_\mu$ (σ_{SM}=631fb)
  - no other tracks attached to the eμ vertex
- signal (N_{tracks}=0) and control (1<=N_{tracks}<=5) regions



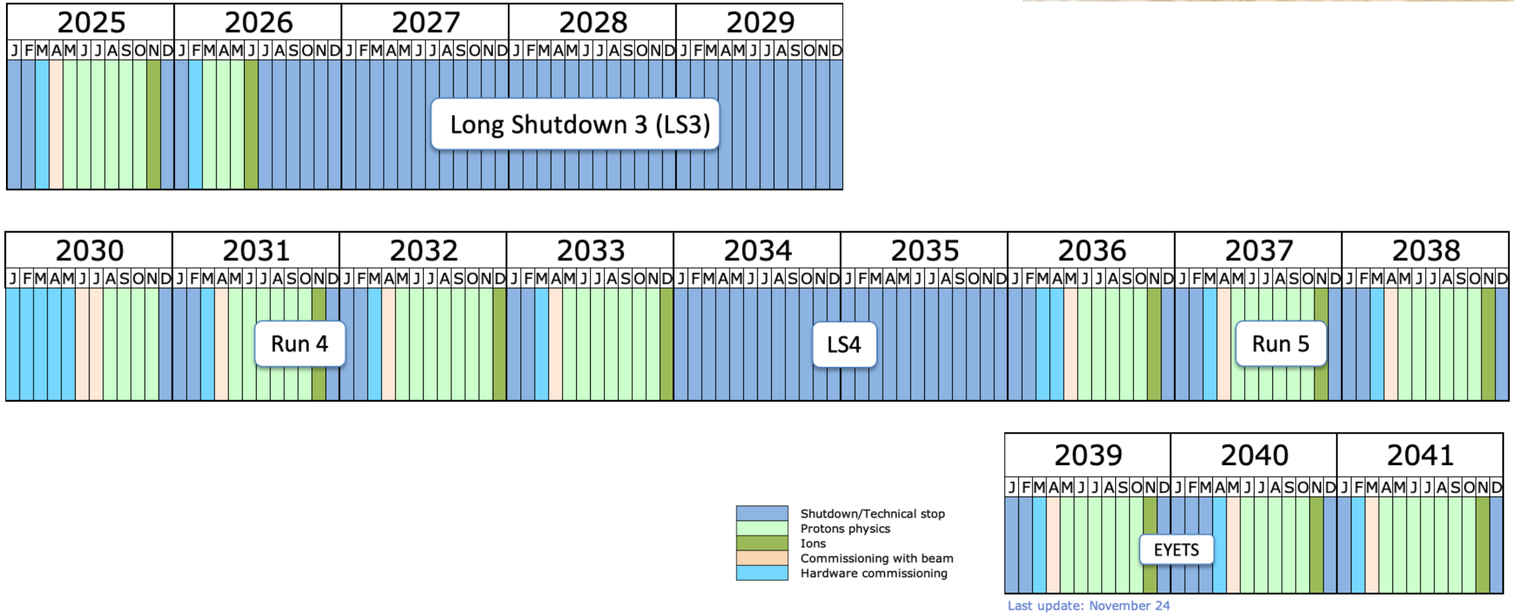
- excellent description of the data by the corrected simulation
  - key technique: reweigh the number of tracks from PU, comparing track counting in data and MC Z→μμ sample



- first observation in CMS: $\sigma(\gamma\gamma \rightarrow W^+W^-)$ = 659 ± 80 fb

The HL-LHC

- successor to the LHC – leap in luminosity
- top priority in 2013 European strategy update
  - approved in 2016
- latest schedule: physics operation starts mid-2030



End of HL-LHC program
Nov 28, 2041 at 6:00am

HL-LHC luminosity scenarios

arXiv:1810.13022, input 2020 EU strategy update

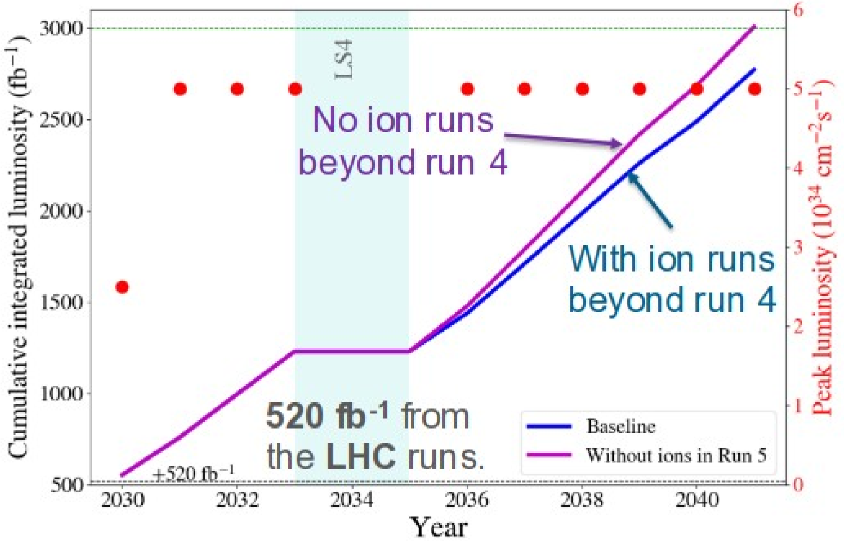
The peak luminosity for the high-luminosity experiments ATLAS and CMS will be levelled at a constant value of around 5×10^{34} cm^{-2}s^{-1} (7.5×10^{34} cm^{-2}s^{-1} ultimate value), in order to limit radiation and event pile-up in the experiments. Expected to operate from 2026 through to the late 2030s, the HL-LHC will increase the integrated luminosity of the LHC by an order of magnitude, yielding a total accumulated value above 3 ab^{-1} (4 ab^{-1} ultimate value).

Chamonix workshop 2025

- baseline scenario now to reach 3 ab^{-1} / experiment delivered luminosity

  of which 520 fb^{-1} from LHC

- ~ 2 ab^{-1} / experiment for physics analysis
  - for 90% recording efficiency



LHC to HL-LHC – what lumi buys us

- for statistics-limited measurements / searches
  - including systematics uncertainties of statistical origin
  - scaling of precision / excess with sqrt ($L_{HL\text{-}LHC}$ / $L_{Run\text{-}3}$)
  - factor ~2.5 gain for lumi increasing from 500 fb^{-1} → 3 ab^{-1}
    - a 2σ hint from Run-3 can grow to observation
- background-free searches
  - scaling sensitivity with $L_{HL\text{-}LHC}$ / $L_{Run\text{-}3}$
  - factor ~6 gain
  - large new phase space for rare processes
- but it's not just luminosity
  - many new detector capabilities
  - many new trigger and data taking opportunities
  - many innovative techniques and improvements

upgraded detectors

analysis technique innovation

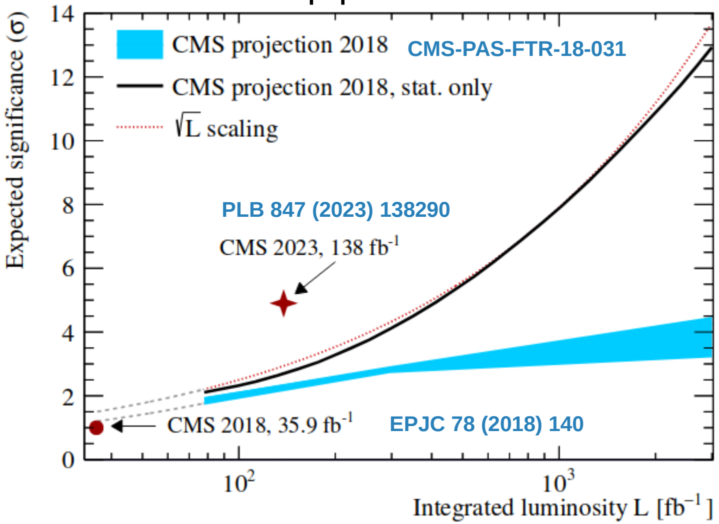
new trigger and data taking

lumi increase

- higher geometrical coverage
- higher resolution
- higher granularity
- precision timing
- radiation hardness
- higher data rate

"Harder, Better, Faster, Stronger"

4-top production

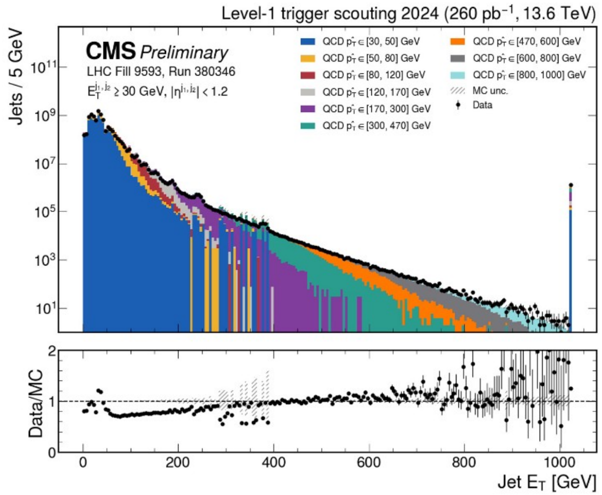


arXiv:2402.07985

new trigger and data taking

upgraded detectors

CMS-DP-2024-056



lumi increase

analysis technique innovation

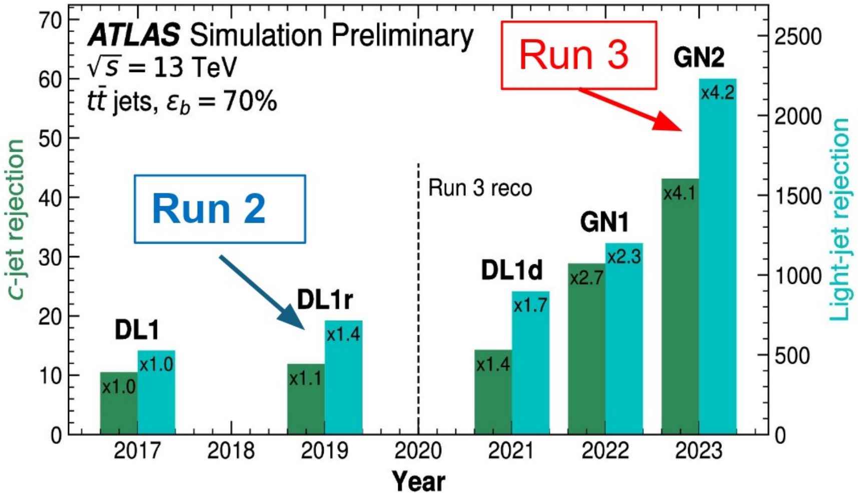
More info in today's CERN seminar:
https://indico.cern.ch/event/1589566/

"Harder, Better, Faster, Stronger"

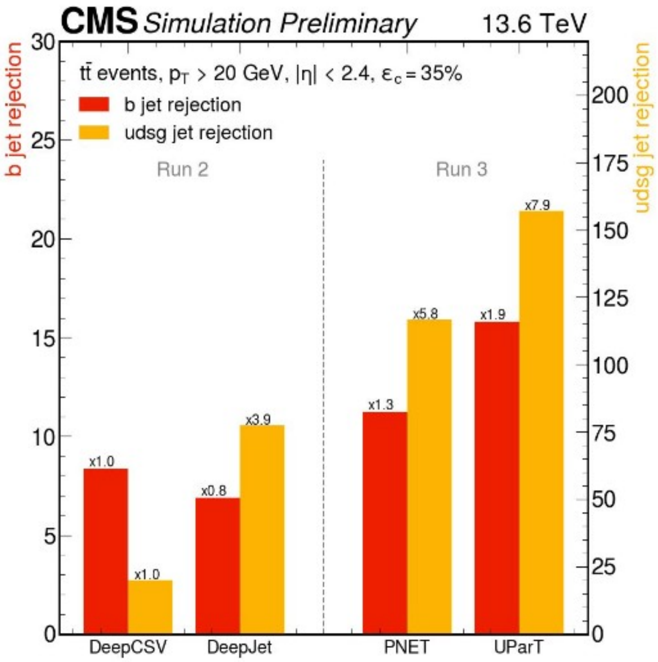
analysis
technique
innovation

- example: absolutely smacking progress in flavour tagging over the 5 past years
  - HL-LHC is >5y away, and will last 10y – where is the limit?

arXiv:2505.19689
FTAG-2023-07

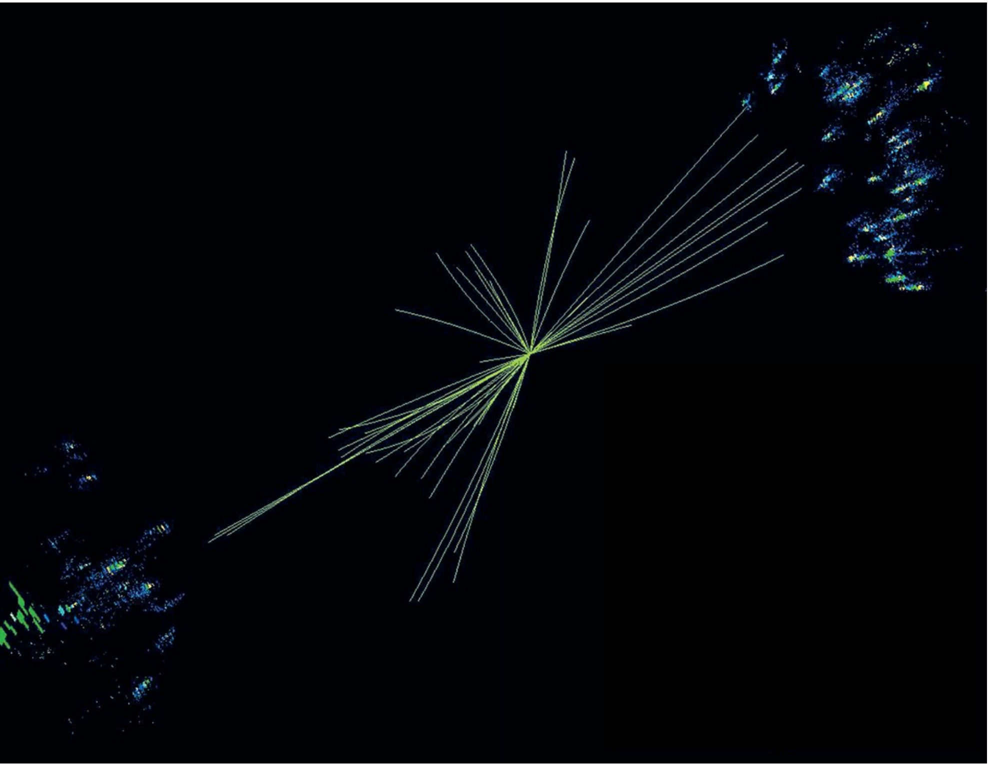


CMS-DP-2024-066



HL-LHC prospects

- some recent developments for the 2026 European Strategy Particle Physics Update
  - arXiv:2504.00672 and Notes cited therein
  - arXiv:2503.24346 and Notes cited therein
- building and expanding on prior results
  - 2021-2022: second Snowmass process
  - 2018-2019: second European Strategy update (Yellow Report)
  - 2015-2022: Phase-2 TP and TDRs



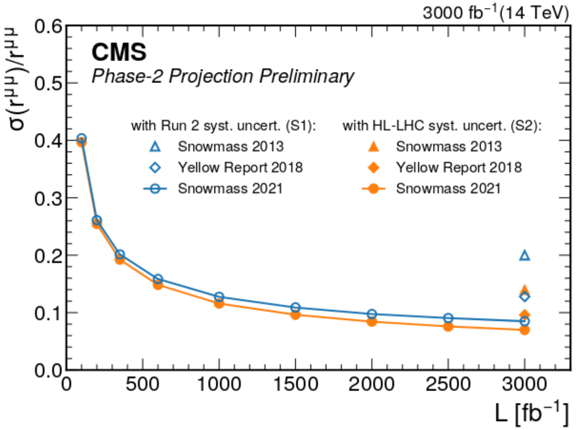
Source: https://cerncourier.com/a/cms-prepares-for-phase-ii/

Rare Higgs processes

CMS-PAS-FTR-21-006

- HL-LHC is a Higgs factory: 380 M in ATLAS+CMS for 3ab^{-1}
  - unique sensitivity to "rare" couplings
- Higgs mass best precision from H → ZZ*
  - 21 MeV ATLAS+CMS expected uncertainty
  - still statistics limited
- H → mumu
  - study details after observation in Run-3
  - 10% acceptance increase in the forward direction
  - boost from 65% better invariant mass resolution
- H → Zgamma
  - guaranteed observation
- H → $c\bar{c}$
  - using VH(cc) only, expect 1.6 sigma ATLAS+CMS
  - $|\kappa_c| < 1.5$ @ 95% CL

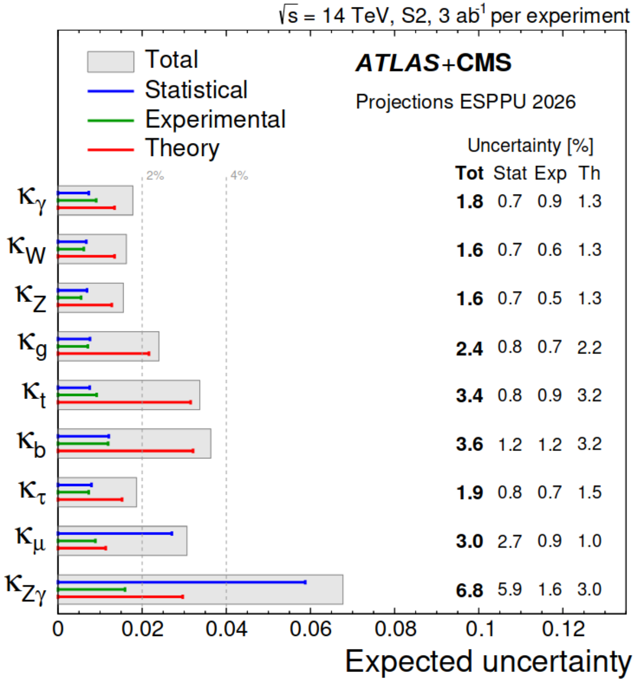
$\mathcal{L}$		$\delta\mu$ [%] $H \to Z\gamma$	$\delta\mu$ [%] $H \to \mu\mu$
2 ab^{-1}	ATLAS	21	13
	CMS	23	8.4
	ATLAS+CMS	15	7.1
3 ab^{-1}	ATLAS	17	11
	CMS	19	7.0
	ATLAS+CMS	14	5.9

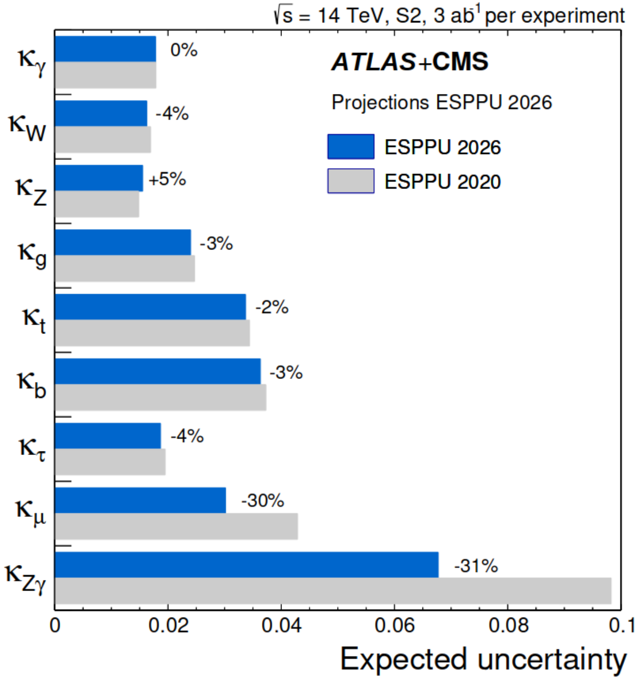


- other opportunities for lasting impact
  - rare decay channels, eg. H → J/ψ γ , H → ϕ γ
  - searches for rare forbidden decays, eg. H → eμ
  - searches for BSM Higgs decays

Higgs couplings

- global fit projected with latest inputs
  - HL-LHC will bring the percent regime for both bosons and fermions
  - theoretically limited!
    - even after assuming factor 2 improvement with respect to now!
    - investment in theory will immediately impact HL-LHC legacy

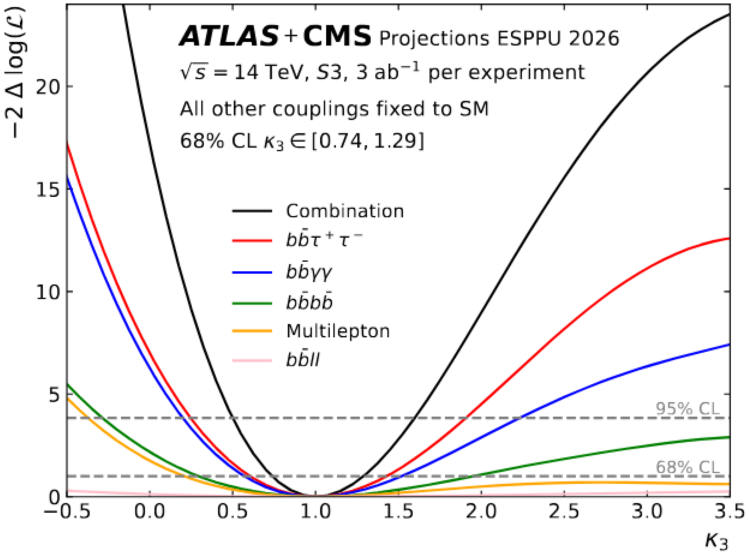


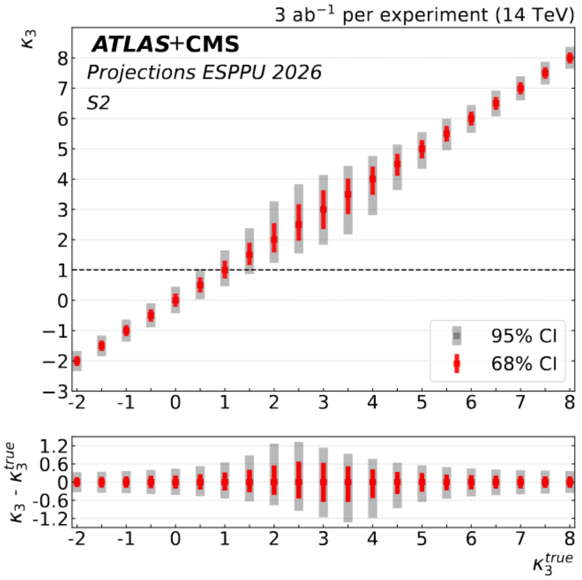


HH searches

- new extrapolation with latest analysis updates
  - incl. 5% improvement on b and τ identification
- bbγγ and bbττ final states dominate sensitivity
- near-observation by experiments individually

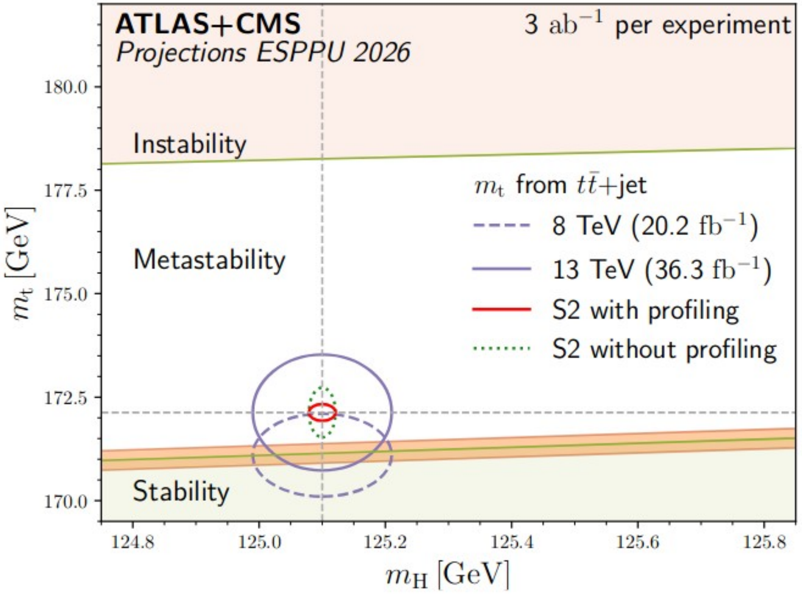
	3 ab^{-1} (S3)	
	ATLAS	CMS
$b\bar{b}\tau^+\tau^-$	3.8†	2.7
$b\bar{b}\gamma\gamma$	2.6†	2.6†
$b\bar{b}b\bar{b}$ resolved	1.0	1.3†
$b\bar{b}b\bar{b}$ boosted	–	2.2†
Multilepton	1.0†	–
$b\bar{b}\ell^+\ell^-$	0.5†	–
Combination	4.5	4.5
ATLAS+CMS	7.6	





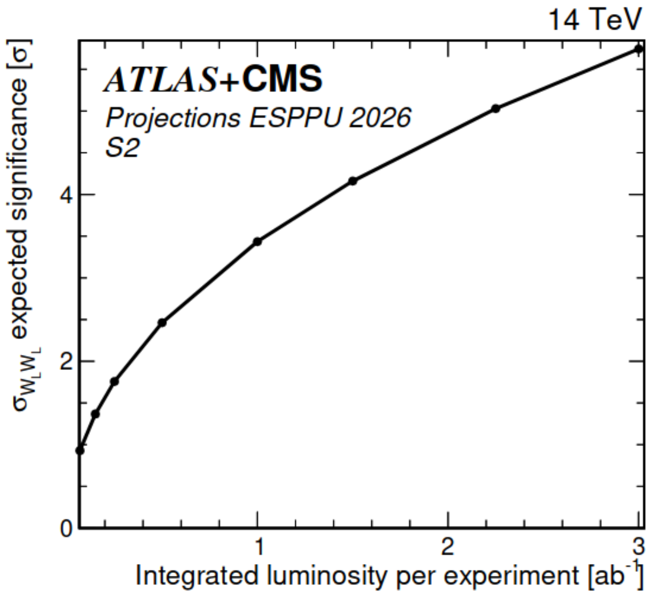
Top mass

- high interest in ultimate pole mass measurement
  - link to the electroweak vacuum stability at the Planck scale
  - test of the SM and potential tensions
  - important (with m_W and m_H) to test BSM effects on EW observables
- the HL-LHC holds a lot of promise for m_{top}
  - ~200 MeV uncertainty in reach
  - theoretical work ahead for interpretation
- from tt+jet cross section measurement
  - systematics determine ultimate sensitivity
- from boosted top decays
  - theoretically closer to pole mass than direct measurements → interpretation work "to do"
  - systematics important, but prospects to balance by going to high-pT region



Rare processes

- another important SM test is $W_L W_L$ vector boson scattering
  - $W_L W_L$ scattering diverges at high E without the Higgs cancellation (or other mechanism)
- same-charge $W_L W_L$ is observable at HL-LHC
- precision 20-40% with $3ab^{-1}$ for $W_L W_L$ component



- $\tau \to \mu\mu\mu$, potentially sensitive to LFV
  - current best limit from Belle-II: < 1.9×10^{-8} @ 90% CL [JHEP 09 (2024) 062]
- extrapolated to $3ab^{-1}$ for CMS and ATLAS
  - both W and heavy-flavour decays can be considered
  - ATLAS: expected < $(1.3–6.4) \times 10^{-9}$ @ 90% CL, depending on assumption background suppression
  - CMS: < 3.9×10^{-9} @ 90% CL
  - detector improvements not fully factored in, will boost further
- LHCb prospect: < 2.6×10^{-9} @ 90% CL
- Belle-II prospects: $(0.2 – 1.7) \times 10^{-9}$ @ 90% CL

Rare processes

CMS-NOTE-2025-004

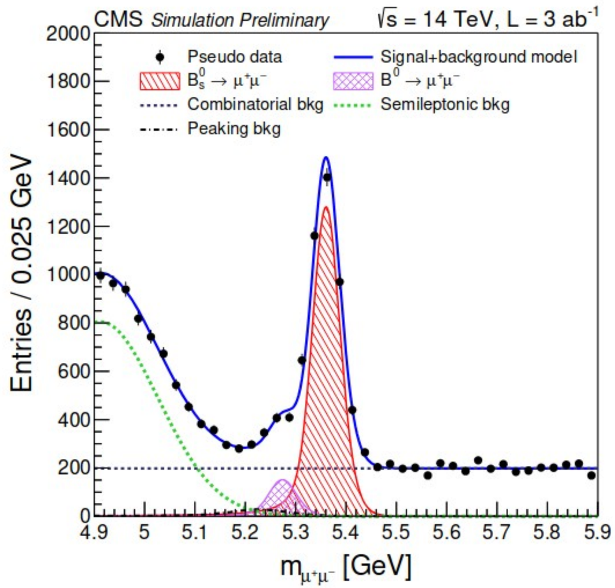
- B_s / B_d → μμ: extremely rare decays
  - BR ~ 3.7 x 10^{-9} for B_s, ~ 1.0 x 10^{-10} for B_d
  - sensitivity to new physics at high scales
  - EFT sensitivities running to the 100s of TeV depending on the considered operator

- large gain from mass resolution improvement

Category	Run 2 [MeV]	Phase 2 [MeV]	Ratio
$B^0_s \to \mu^+\mu^-$, central-μ	37	26	1.4
$B^0_s \to \mu^+\mu^-$, forward-μ	56	37	1.5
$B^0 \to \mu^+\mu^-$, central-μ	37	26	1.4
$B^0 \to \mu^+\mu^-$, forward-μ	56	37	1.5

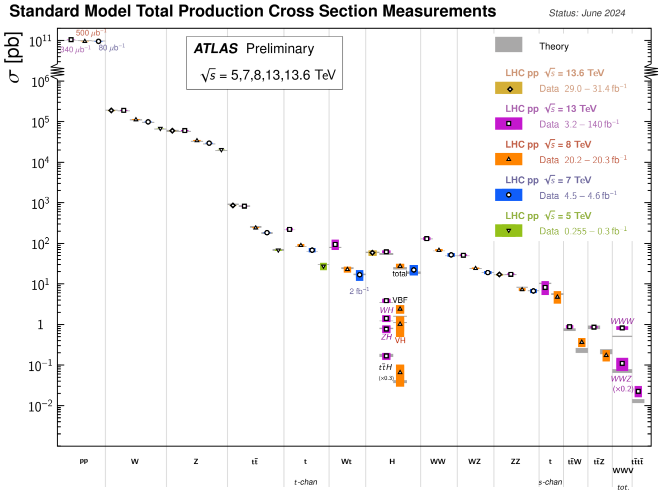
- reach with 3ab^{-1}
  - 6% precision on B_s → μμ branching fraction
  - 12% precision on B_d → μμ branching fraction

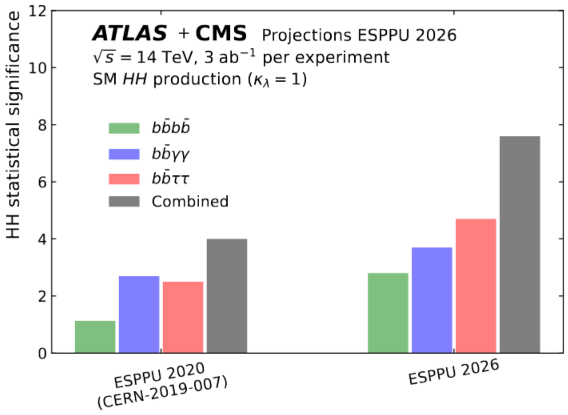
- LHCb reach with 50fb^{-1}:
  - 4% precision on B_s → μμ branching fraction
  - 12% precision on B_d → μμ branching fraction



Conclusions

- LHC continues to deliver beyond expectation
  - excellent accelerator performance
  - efficient high-quality data taking
  - new opportunities from innovative triggering
  - impressive improvements in analysis techniques
- physics results keep pushing boundaries
  - Run-2 wrapping up, Run-3 full exploration still to start



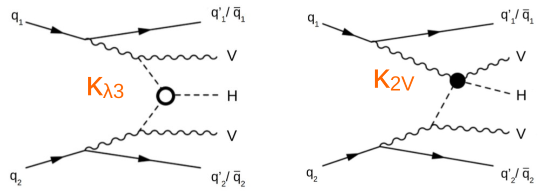


- the HL-LHC brings unprecedented capabilities
  - state-of-the-art detectors being constructed
  - game-changing new triggers and data taking techniques
  - 15y of analysis technique innovation ahead
- full potential is a story that is yet to unfold
  - enhanced “LHC program” plus new opportunities
  - examples from Higgs, top, EW, B-physics, BSM

Backup

Search for VVH

CMS-PAS-HIG-24-003

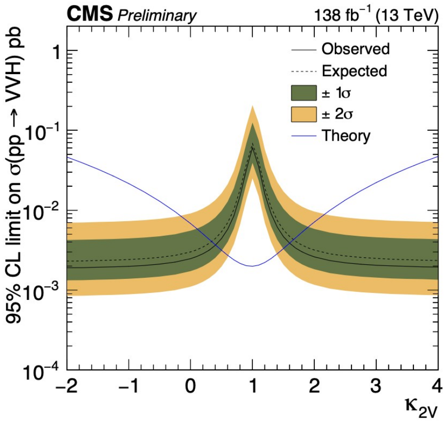


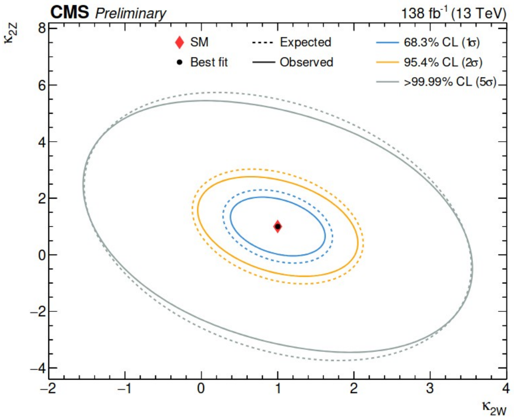
- H → $b\bar{b}$ (with $b\bar{b}$ boosted) + 2 jets (VBF) + 0,1,2 leptons from V-decays
  - boosted $b\bar{b}$/qq jets tagged with ParticleNet algorithm
  - categorize in final states with leptons or boost
- DNN/BDTs trained using κ_{2V}=2 benchmark against SM
- background from ABCD method
  - using forward VBS jets versus central activity
  - decorrelation of DNN/BDT scores from forward activity (in particular $\Delta\eta_{ij}$ of forward jets used in ABCD)

95% CL limits on quartic coupling modifier κ_{2V}

- $0.40 < \kappa_{2V} < 1.60$ ($0.34 < \kappa_{2V} < 1.66$ exp.)
- assuming SM for other couplings
- alse sensitivity to WWHH and ZZHH separately

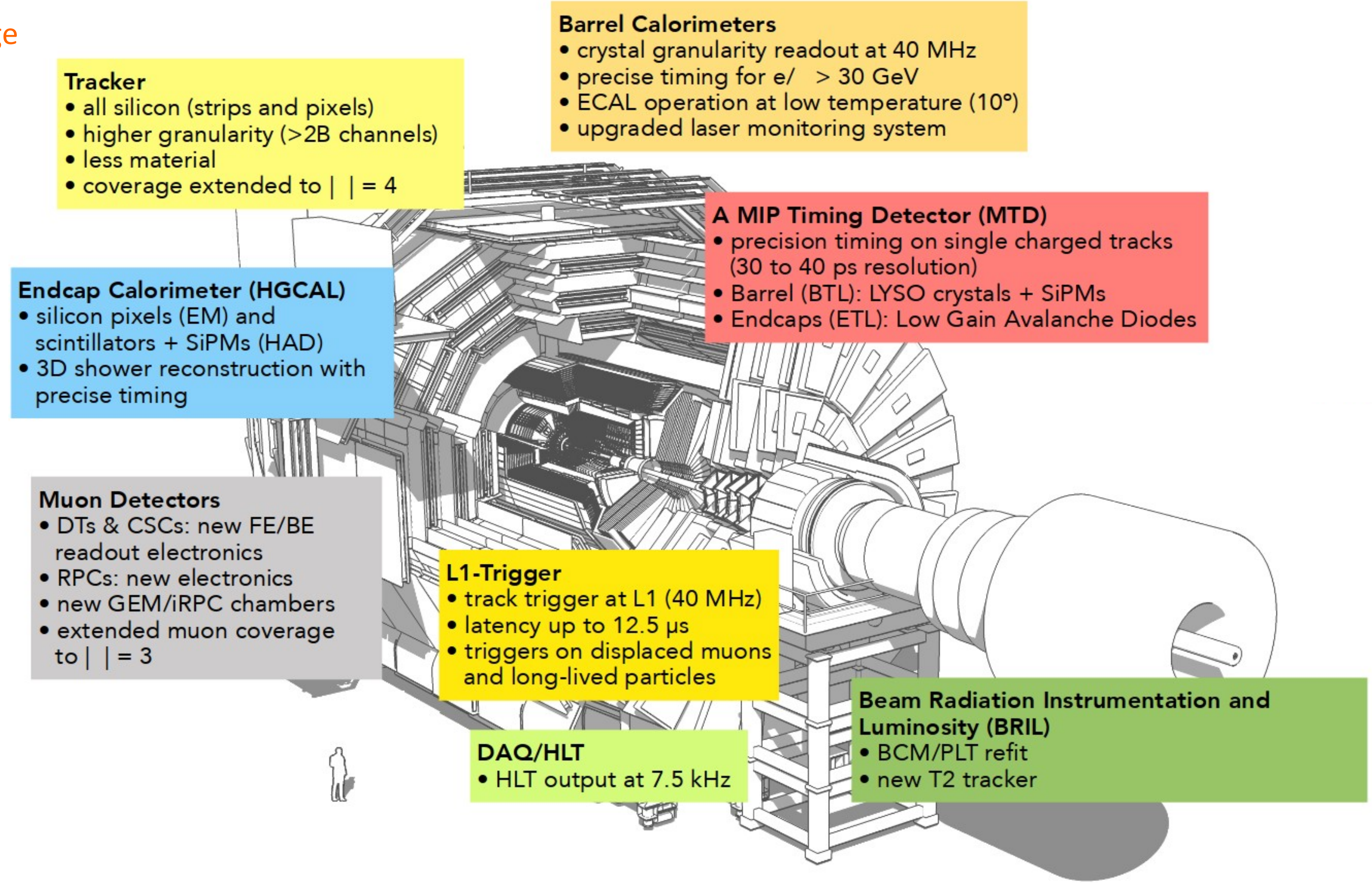
	All-hadronic		Semileptonic	2 Leptons	
	fully boosted	semi-boosted		OS WW	Z
Region B data	1	410	3	2	1
Region C data	73	399	61	10	5
Region D data	654	15974	1039	179	17
Region A data	0	7	0	0	0
Region A pred.	$0.11^{+0.26}_{-0.09}$ (stat.) ± 0.03 (syst.)	$10.24^{+0.78}_{-0.72}$ (stat.) ± 1.95 (syst.)	$0.18^{+0.18}_{-0.10}$ (stat.) ± 0.06 (syst.)	$0.11^{+0.18}_{-0.08}$ (stat.) ± 0.02 (syst.)	$0.29^{+0.91}_{-0.25}$ (stat.) ± 0.21 (syst.)
Region A signal ($\kappa_{VV} = 2$)	3.30 ± 0.02 (stat.) ± 1.01 (syst.)	1.06 ± 0.01 (stat.) ± 0.36 (syst.)	2.79 ± 0.02 (stat.) ± 0.84 (syst.)	0.31 ± 0.01 (stat.) ± 0.10 (syst.)	$0.22 \pm (< 0.01)$ (stat.) ± 0.07 (syst.)
Region A signal (SM)	0.04 ± 0.01	$0.01 \pm (< 0.01)$	0.04 ± 0.02	$0.01 \pm (< 0.01)$	$(< 0.01) \pm (< 0.01)$





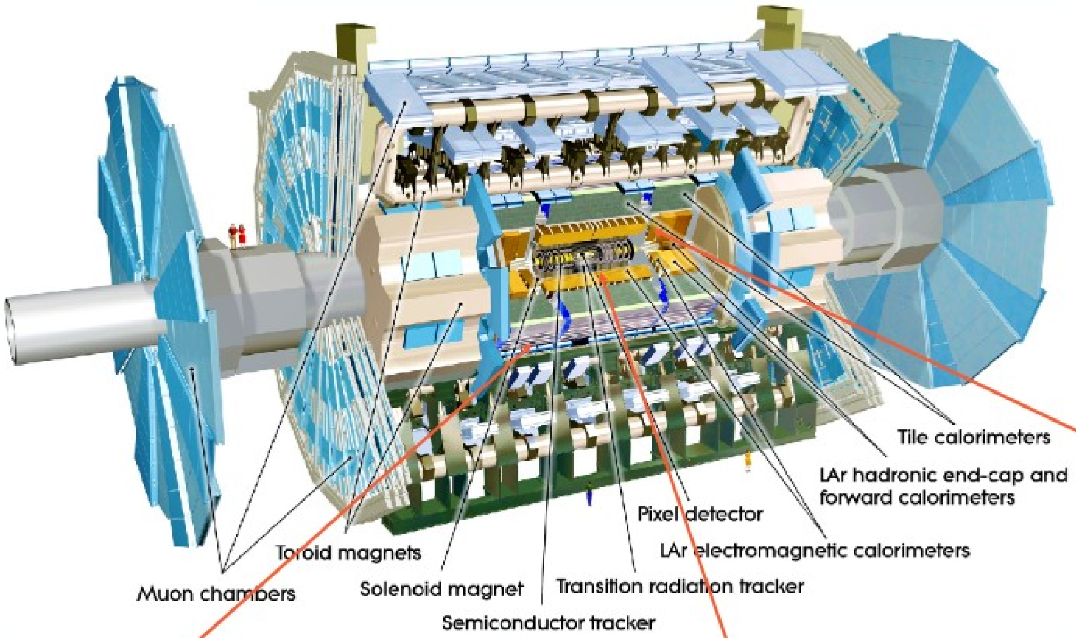
A bold and ambitious upgrade program

- higher geometrical coverage
- higher resolution
- higher granularity
- precision timing
- radiation hardness
- higher data rate



- paradigm shifts
  - track trigger at Level-1
  - PF and ML at Level-1
  - imaging calorimetry
  - sub-100ps timing
  - …

Slide for ATLAS upgrade details



Upgraded Trigger and Data Acquisition system

Level-0 Trigger at 1 MHz

Improved High-Level Trigger

(150 kHz full-scan tracking)

Electronics Upgrades

LAr Calorimeter

Tile Calorimeter

Muon system

High Granularity Timing Detector (HGTD)

Forward region ($2.4 < |\eta| < 4.0$)

Low-Gain Avalanche Detectors (LGAD)

30 ps track resolution

New Muon Chambers

Inner barrel region with new RPC and sMDT detectors

New Inner Tracking Detector (ITk)

All silicon, up to | | = 4
High-granularity Pixel and Strip systems

Additional upgrades

Luminosity detectors (1% precision goal)

HL-ZDC

Offline software and computing

s-tagging

s-tagging performance

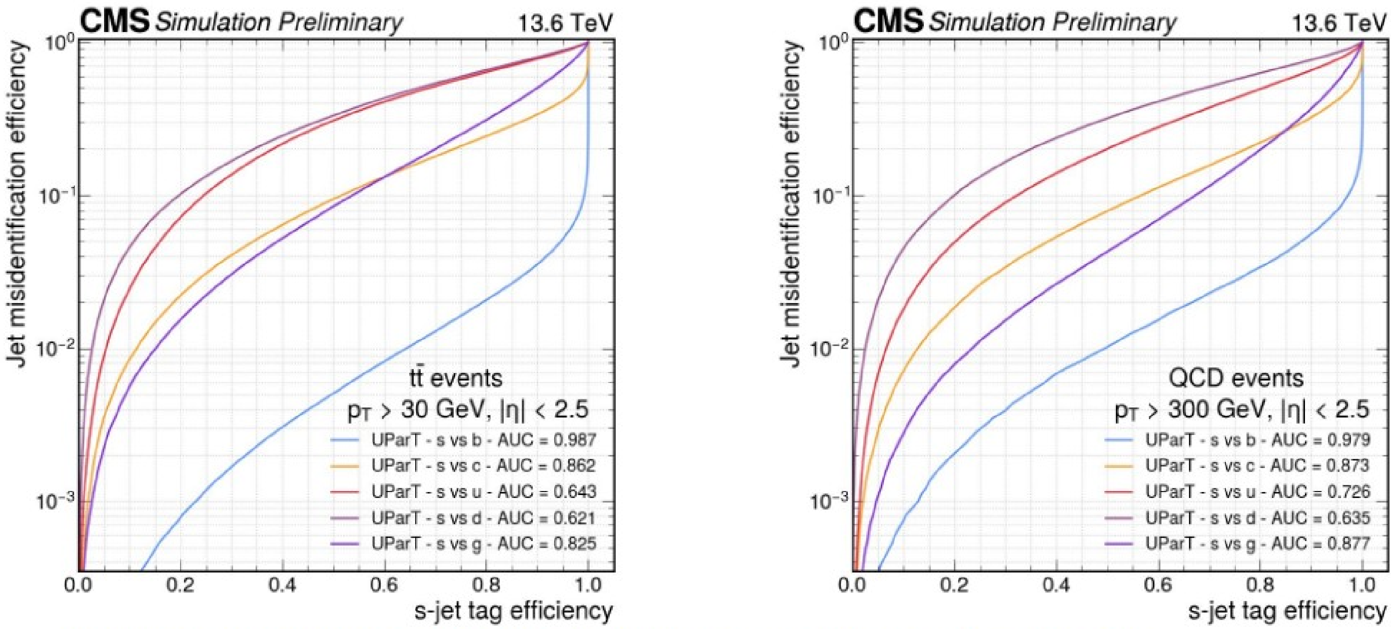


Figure 4: s-tagging ROC curves. It's the first time a specific s-node is added to a jet tagging algorithm in the CMS experiment. Performances indicates we can achieve a low efficiency s-tagger.

$$\mathrm{S\ vs\ X} = \frac{prob(S)}{prob(S) + prob(X)}$$