Highlights of physics results from ATLAS and CMS

Tatiana Lyubushkina[1]
on behalf of ATLAS and CMS Collaboration

[1]Joint Institute for Nuclear Research
Tatiana.Lyubushkina@cern.ch







The 8th International Conference on Particle Physics and Astrophysics

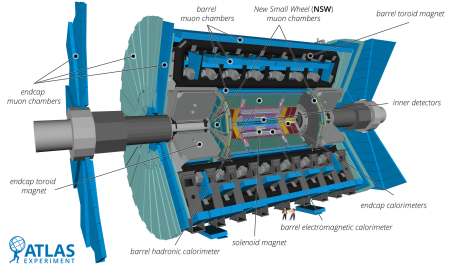
Moscow, Russia
27 – 30 October 2026

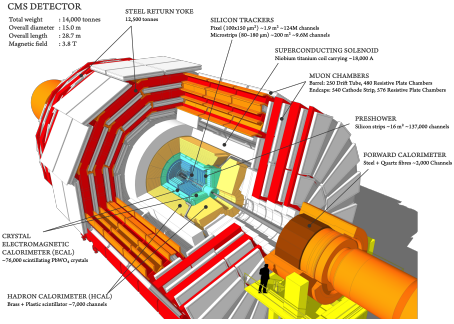
Outline

Both experiments feature a rich physics programme

- Higgs Physics
- Standard Model
  - Precision QCD, electroweak
- Top Physics
- Heavy-flavour physics
  - Spectroscopy, fragmentation, CP violation, Rare decays
- Beyond the Standard Model physics
- Heavy Ion Physics (talk by Sergey Petrushanko)

Explore $\sim$ 3000 **ATLAS** and **CMS** physics papers



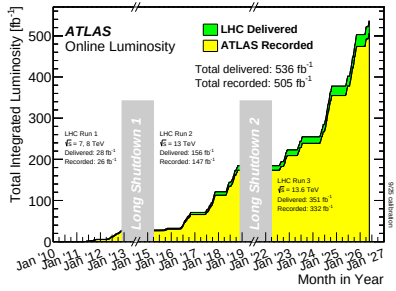


Data-taking highlights

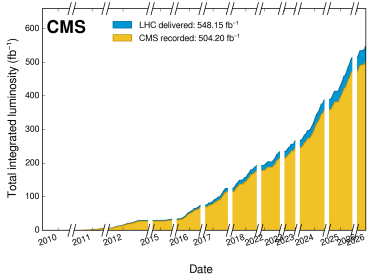
- Run 3 successfully completed:
  - Data taking officially concluded on June 29, 2026, marking the end of the third LHC run.
  - Completed on August 31, 2026, transitioning the CERN accelerator complex into Long Shutdown 3 (LS3).
- Legacy Run 3 dataset:
  - Delivered an outstanding ~ 351 fb^{-1} of proton-proton collision data (with $\sim 92\%$ recording efficiency), alongside reaching full heavy-ion goals.
- More than 500 fb^{-1} of proton-proton collisions have been delivered to both ATLAS and CMS since the beginning of regular LHC physics operations

25 fb^{-1} (7 & 8 TeV) | 156 fb^{-1} (13 TeV) | 351 fb^{-1} (13.6 TeV)

ATLAS Luminosity Public Results

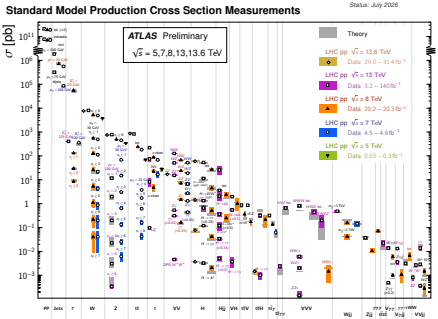


CMS Luminosity Public Results

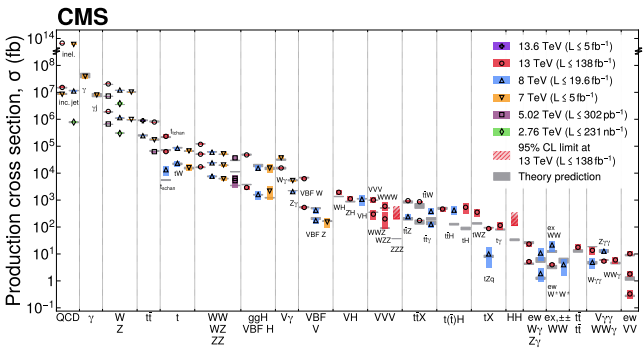


Probing the Standard Model of particle physics

SM is extremely successful in describing collider-based measurements over many orders of magnitude (from soft QCD to rare EW production)



SM summary plots



Physics Report 1115 (2025) 3

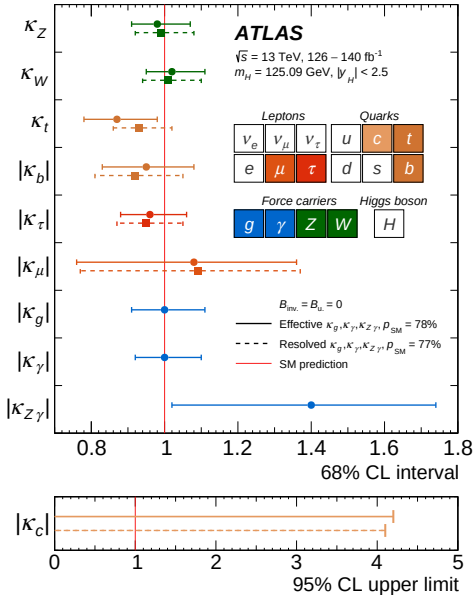
Collider-experiments: probing the SM broadly and deeply across all its sectors

Higgs boson properties in focus

Detailed and precise measurements of Higgs production, decays, and couplings from combination of 26 single and di-Higgs analyses from ATLAS

- Couplings to W, Z, t, b, τ measured to 5-12%
  - κ **framework** to measure multiplicative modifiers to the coupling strengths, assuming kinematic distributions are preserved: $\kappa_p^2 = \sigma_p/\sigma_p^{\mathrm{SM}}$
- Charm coupling constrained to $|\kappa_c| < 4.1$ at 95% CL
- $\mathcal{B}(H \to \mathrm{inv}) < 12$ % at 95% CL
- Higgs boson width $\Gamma = 3.6^{+2.1}_{-1.6}$ MeV
- Self-coupling constrained to $-1.5 < \kappa_\lambda < 6.5$ at 95% CL based on single and di-Higgs analyses
- Includes also differential measurements for the main production processes

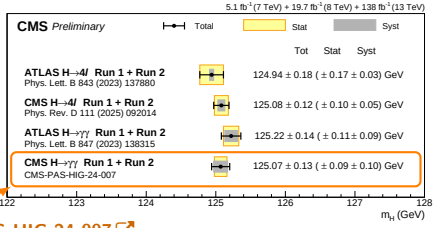
arXiv:2608.07332, Run 2



Higgs boson properties in focus

The statistical combination is based on analyses that measure the following decay channels: $H \to \gamma\gamma$, $H \to ZZ$, $H \to WW$, $H \to \tau\tau$, $H \to bb$, $H \to \mu\mu$, $H \to Z\gamma$ (Run 2)

- Coupling precisions 5% for EW bosons, 10% for 3rd generation fermions and 6-7% for massless bosons
- Invisible $\mathcal{B} < 12\%$; undetected $\mathcal{B} < 30\%$
- Best limits on the charm quark coupling: $|\kappa_c| < 3.5$
- $\Gamma = 5.0^{+2.0}_{-1.8}$ MeV [CMS-HIG-25-003]



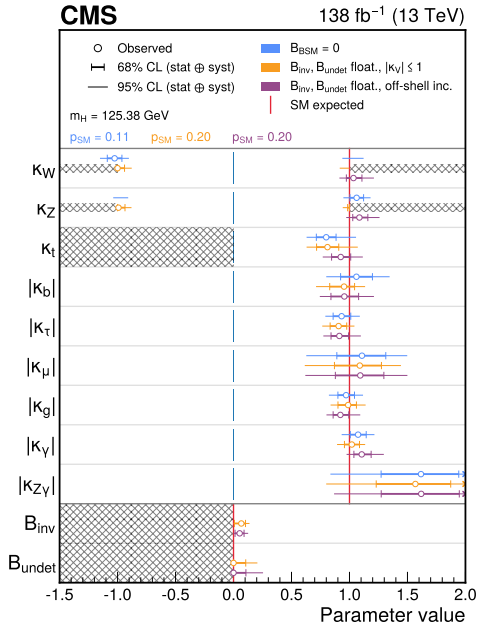
CMS-PAS-HIG-24-007

Most precise to date ATLAS $H \to \gamma\gamma$ & $H \to 4\ell$ (Run 1+Run 2):

$m_H = 125.11 \pm 0.09(\text{stat.}) \pm 0.06(\text{syst.})$ GeV

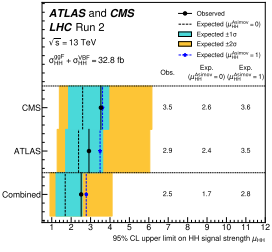
Phys.Rev.Lett. 131 (2023) 251802

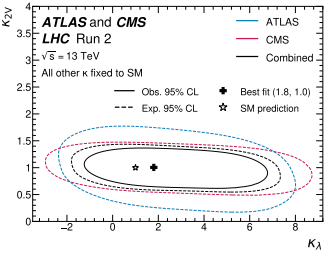
Rep. Prog. Phys. 89 (2026) 087801



Di-Higgs production

- Probe of Higgs self-coupling: crucial to understand the nature of the EW phase transition and the stability of the EW vacuum, important test of the Higgs potential shape
- First combination of ATLAS and CMS Higgs pair-production searches [Phys.Rev.Lett. 137 (2026) 13, 131803]
- Best-fit of the signal strength is $0.8^{+0.9}_{-0.7}$, with obs. (exp.) significance 1.1 (1.3)



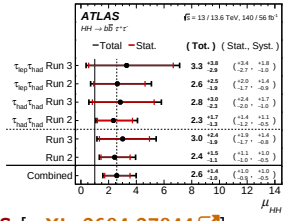


- Observed and expected 95% CL contours for the simultaneous scan of the profile likelihood as a function of κ_λ and κ_{2V}

  $\kappa_\lambda = \lambda/\lambda^{SM}$ (trilinear self-coupling),
  $\kappa_{2V} = c_{HHVV}/c^{SM}_{HHVV}$ (coupling of two Higgs bosons to two vector bosons)

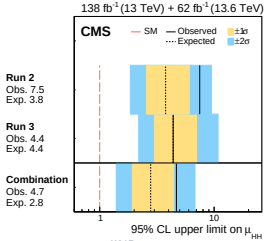
New ATLAS [arXiv:2607.26879]

- $HH \to bb\tau\tau$, Run 2+2022+2023
- Signal strength $\mu_{HH} = 2.6^{+1.4}_{-1.0}$, significance 2.6σ obs. (1.2σ exp.) – sensitivity close to Run 2 ATLAS+CMS combined result



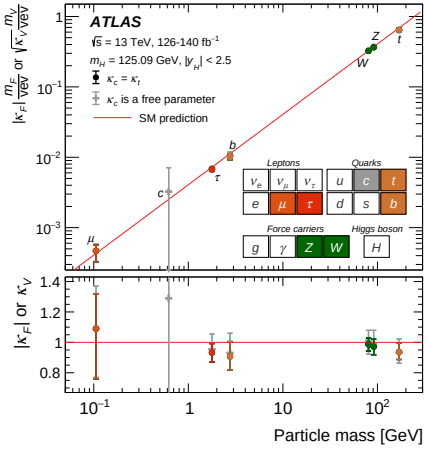
New CMS [arXiv:2604.27044]

- $HH \to bbbb$, Run 2+2022+2023
- Observed (exp.) upper limit μ_{HH} 4.7 (2.8) at 95% CL – the most stringent constraints from 4b final state to date



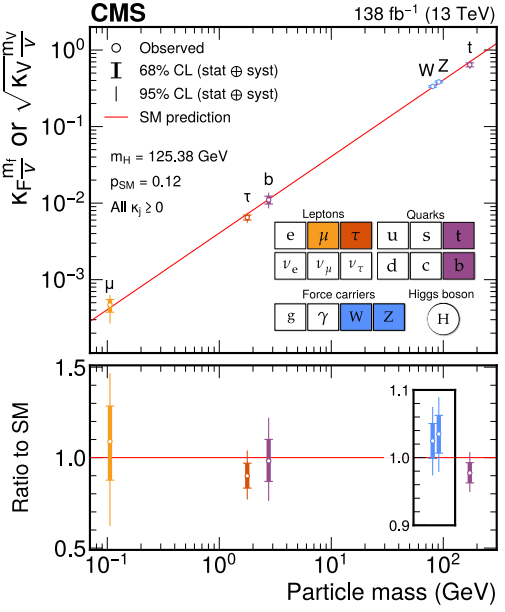
Higgs boson properties in focus

arXiv:2608.07332



- Our understanding of the Higgs boson (and the Standard Model) is getting gradually more precise
- What can we expect for HL-LHC – Projection of observation of HH in each experiment, with 3 ab^{-1}

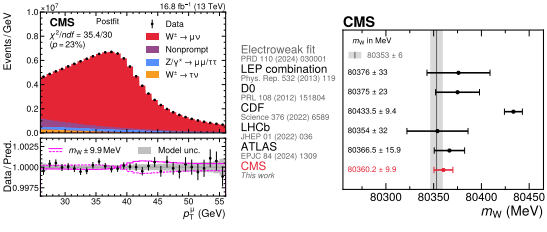
Rep. Prog. Phys. 89 (2026) 087801



W boson measurements (CMS)

High-precision measurement of the W boson mass [Nature 652, 321–327 (2026)]

- Uses 13 TeV data from 2016 (**Run 2**)

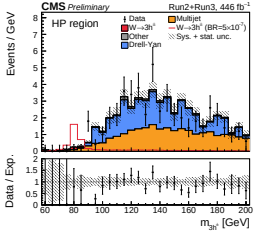


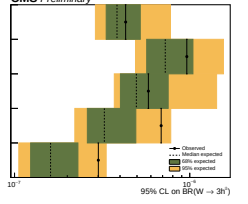
$$m_W = 80360.2 \pm 9.9 \text{ MeV}$$

- Uncertainty comparable to CDF
- Good agreement with results of the EW fits

Search for $W \to 3h$ [SMP-25-011]

- Uses (**Full Run 2 + Run 3 data 2016-2026**)
- Rare decay, no precise theoretical prediction
- Estimate: $\mathcal{B}(W^\pm \to 3\pi^\pm) \sim \mathcal{O}(10^{-7} - 10^{-5})$





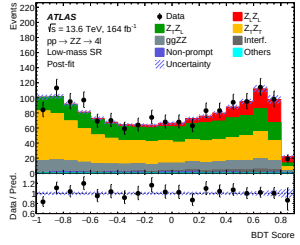
- Combined result: $\mathcal{B}(W \to 3h) < 2.4 \times 10^{-7}$ at 95% CL
- Four times better than previous results

Gauge boson polarization: inclusive ZZ and VBS WZ (ATLAS)

arXiv:2607.12879, arXiv:2607.20246

Gauge boson longitudinal polarization closely related to EW symmetry breaking

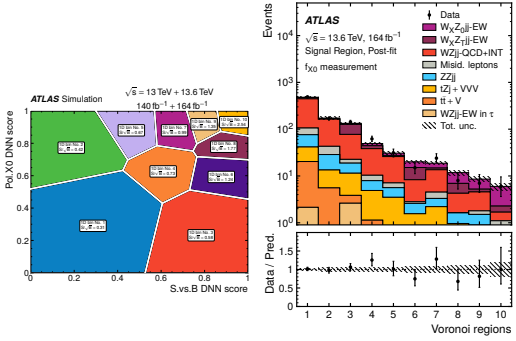
- Goldstone equivalence theorem: at high energy scale Goldstone bosons $\longleftrightarrow$ longitudinally polarized gauge bosons
- Study of inclusive ZZ production
- Using **2022-2024** data and combining with **Run 2**
- Inclusive polarization fraction



$$f_{LL} = 0.080 \pm 0.017$$

- Combination with Run 2 data: 6.5σ (5.6σ exp.) for $Z_L Z_L$ production – first observation

- Vector-boson scattering unitarized by Higgs couplings
- Joint analysis of **Run 2 + 2022-2024**:



- Joint analysis of Run 2 + 2022-2024: 4.0σ (2.9σ exp.) for WZ_{Ljj} – first evidence

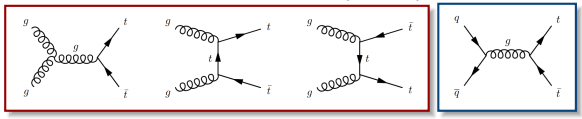
Top quark physics at the LHC

- Precise measurements of top-quark properties probe the SM and theoretical predictions
  - Largest mass of any fundamental particle – The top quark mass m_t is a fundamental parameter, sensitive to EW physics
  - Yukawa coupling ~ 1
  - Decays before it hadronises
  - Structure of the CKM matrix, couplings and higher-order effects can be probed via top decays

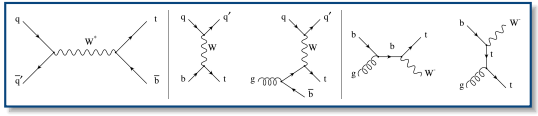
LHCTopWGSummaryPlots:

Basic production modes:

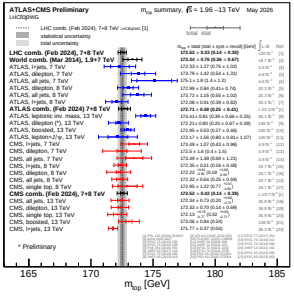
QCD $t\bar{t}$ pair production: gg-fusion ($\sim 90\%$), qq annihilation

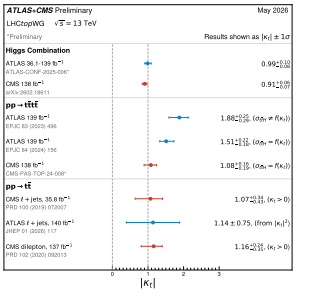


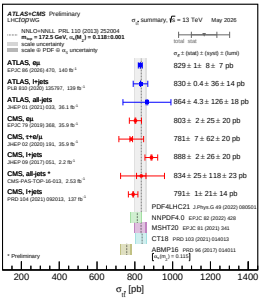
EW production of single top quarks



s-channel *t*-channel associated *tW*







$|V_{cb}|$ CKM matrix element in $t\bar{t}$ events (ATLAS)

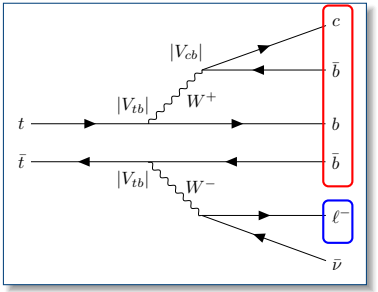
JHEP 07 (2026) 078, Run 2

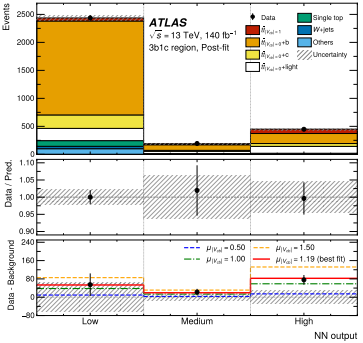
- SM does not predict the values of its elements, precise experimental determinations enable stringent tests of this unitarity and, consequently, the internal consistency of the SM
- First $|V_{cb}|$ measurement in top quark decays: on shell W bosons

$$|V_{cb}|^2 = \frac{|V_{cb}|^2}{\sum_q |V_{cq}|^2} = \frac{\mathcal{B}(W^+ \to c\bar{b})}{\mathcal{B}(W^+ \to c\bar{q})} = \frac{\mathcal{B}(t \to b\bar{b}c)}{\mathcal{B}(t \to b\bar{q}c)}$$

- Complementary to bound-state B meson measurements
- $t\bar{t}$ events with a single lepton + four jets in the final state
  - 8 tagging categories defined, based on numbers of tagged b- and c-jets in 4-jet events
  - NN separation of signal from background, with in-situ c-tagging calibration

$$|V_{cb}| = 50^{+7}_{-9}(\text{stat.})\ ^{+9}_{-10}(\text{syst.}) \times 10^{-3}$$



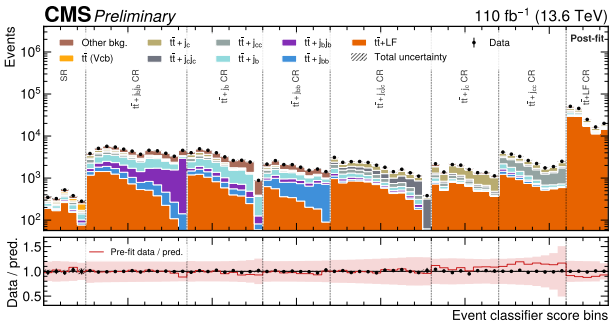


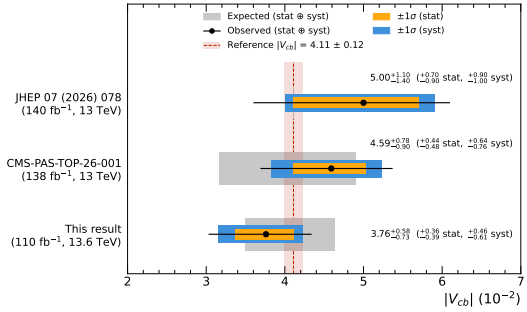
$|V_{cb}|$ CKM matrix element in $t\bar{t}$ events (CMS)

CMS-PAS-TOP-26-002, Run 3 (2024)

- New $|V_{cb}|$ analysis from CMS
- Complementary to B-physics measurements; probe at EW scale
- The identification of c and b quark-initiated jets using the Unified Particle Transformer (UParT)
- Distinguish the signal from various $t\bar{t}$ background processes – machine learning classifier based on the Particle Transformer (ParT) architecture
- 7 control regions
- Background: $t\bar{t}$ +jets

$$|V_{cb}| = 3.76^{+0.36}_{-0.39}(\text{stat.})\ ^{+0.46}_{-0.61}(\text{syst.}) \times 10^{-2}$$



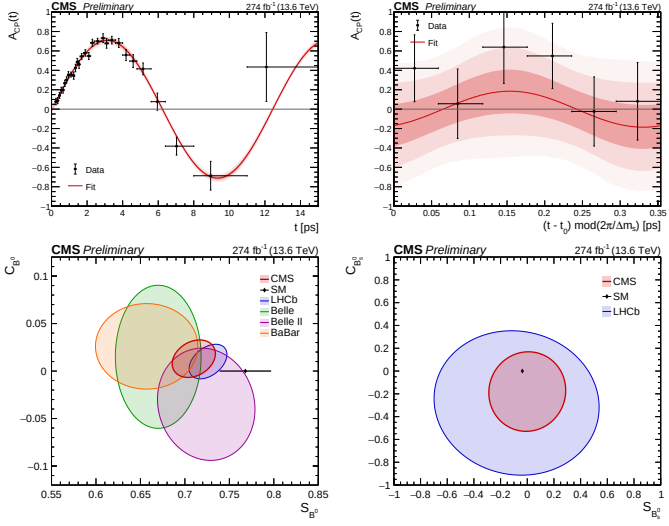


Measurement of time-dependent CP violation in $B^0_{(s)} \to J/\psi K^0_s$

BPH-26-005, **Partial Run 3 (2022-2025)**

$$a_{CP}(t) = \frac{S_f \sin(\Delta m \cdot t) - C_f \cos(\Delta m \cdot t)}{\cosh\left(\frac{\Delta\Gamma \cdot t}{2}\right) - D_f \sinh\left(\frac{\Delta\Gamma \cdot t}{2}\right)}$$

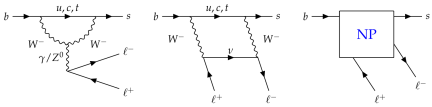
- Clean way to access CKM phase sin(2β) from the time-dependent CP asymmetry (the first CMS measurement)
- Testing the SM and searching BSM through loop effects in neutral B mixing
  - Mixing-induced (S_f) and direct CP violation effects (C_f).
- The world's best precision for the time-dependent CP-violation in $B^0_s \to J/\psi K^0_s$ decays, which is used to improve control of the penguin contribution to sin(2β)
- This result is based on a new analysis framework that is transferable and scalable to multiple measurements



Compatible precision to the world's best measurement from LHCb

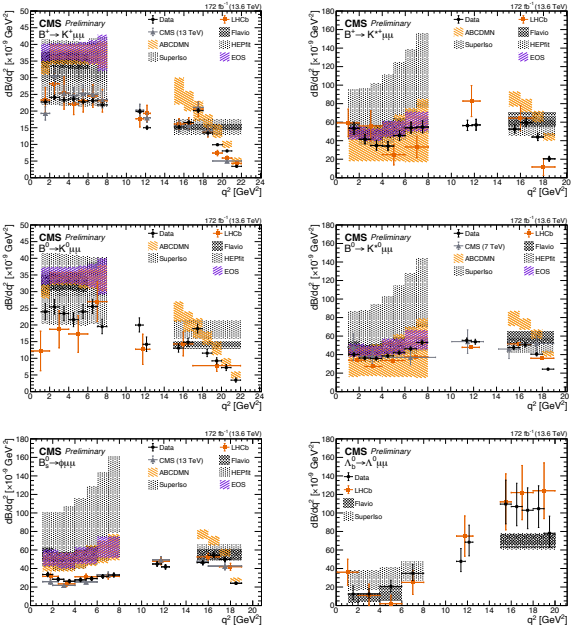
$b \to s\mu\mu$ differential branching ratios

BPH-24-005, Partial Run 3 (2022-2024)



- $b \to s\ell\ell$: Flavor - Changing Neutral Currents (FCNCs)
- Transitions are forbidden in SM at tree level and proceed only through higher-order electroweak loop diagrams $\Longrightarrow$ highly suppressed: $\mathcal{B} \sim 10^{-7}$ sensitivity to new physics
- Six different channels measured simultaneously – most precise measurements to date
- Also measured: isospin asymmetry, $R(\psi(2S))$

Results in agreement with previous CMS & LHCb results



Observation of a B_c^{*+} meson

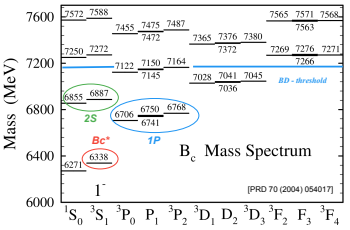
Phys. Rev. Lett. 137 (2026) 141901, Run 2

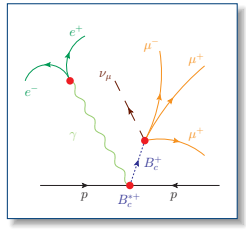
Testing the strong sector of the SM

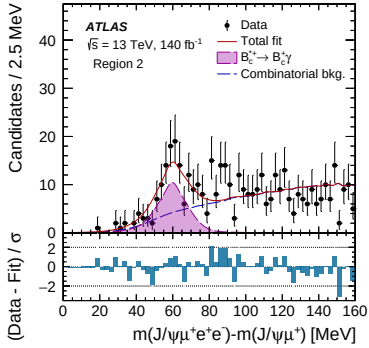
- The lightest B_c^{*+} excitation, 1^3S_1 state, is abundant but challenging experimentally:
  - $M(B_c^{*+}) - M(B_c^+)$ predicted to be ∼50–70 MeV → very soft photon in $B_c^{*+} \to B_c^+\gamma$
- Semileptonic channel for B_c^+ reconstruction
- Soft converted photons reconstructed from tracks down to 100 MeV on preselected set of events
- New state observed with $> 8\sigma$ significance

$$\Delta m(B_c^{*+}) = 64.5 \pm 1.4(\text{stat.})\ ^{+1.0}_{-1.4}(\text{syst.})\ \text{MeV}$$

- In agreement with theory predictions based on QCD potential models
- Larger than recent lattice QCD calculations





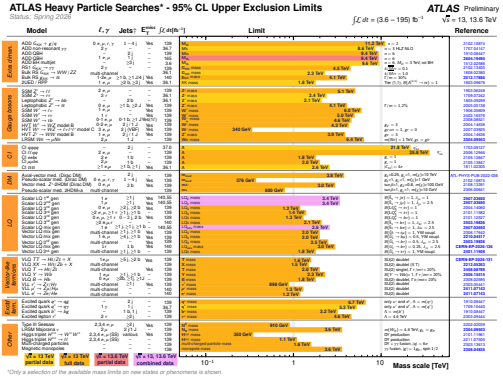


A lot of open questions

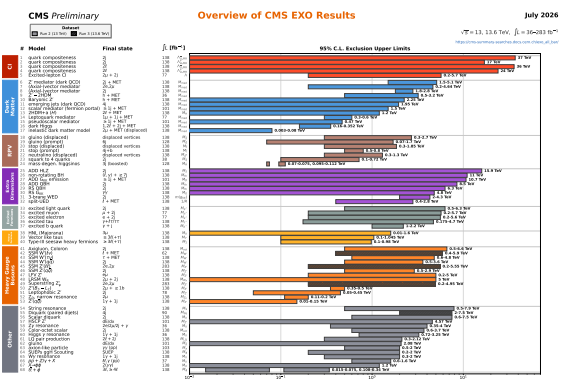
- What is dark matter?
- Origin of the matter/antimatter asymmetry?
- Why 3 fermion generations?
- Hierarchy problem?
- Nature of EW phase transition?

Searching for BSM particles and phenomena

ATLAS Searches Summary Plots



CMS Searches Summary Plots



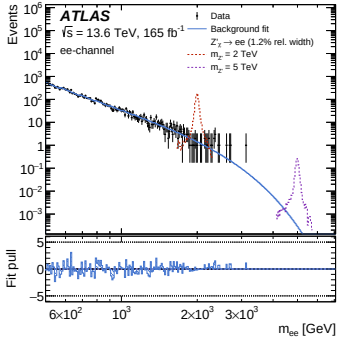
BSM: Search for dilepton resonances

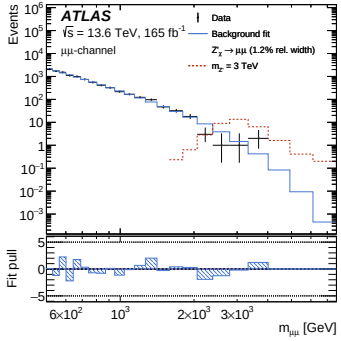
arXiv:2607.28334, Partial Run 3 (2022-2024)

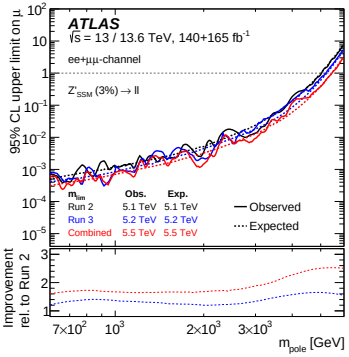
Search for high-mass Z' vector boson: Sequential SM Z', GUT Z'_χ and Z'_ψ

- Analysis:
  - two high-pT leptons (electrons or muons),
  - background dominated by Drell-Yan,
  - bump hunting over smooth background spectra, modeled using analytical functions
- Results:
  - No globally significant deviation from the background-only hypothesis
  - Limits on Sequential SM and E6-motivated grant unification model

Lower mass limits when combined with Run 2 search: Z'_{SSM}(5.5 TeV), Z'_χ(5.1 TeV), Z'_ψ(4.8 TeV)







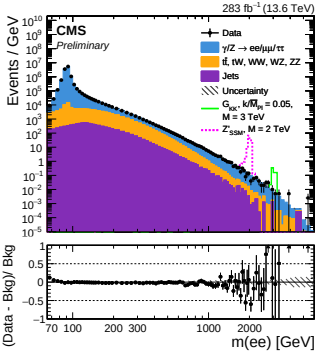
BSM: Search for dilepton resonances

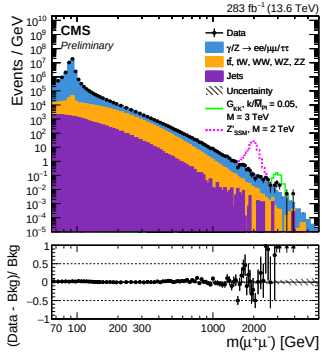
CMS-PAS-EXO-25-021, **Partial Run 3 (2022-2025)**

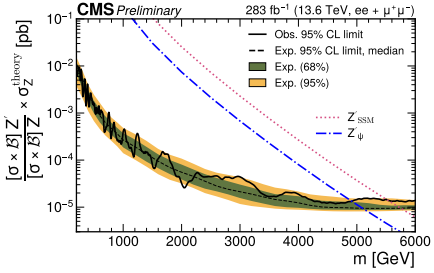
Search for resonances between 200-6000 GeV in the dilepton (ee, $\mu\mu$) mass spectra, explore SSM and GUT Z' and Kaluz-Klein graviton G_{KK}

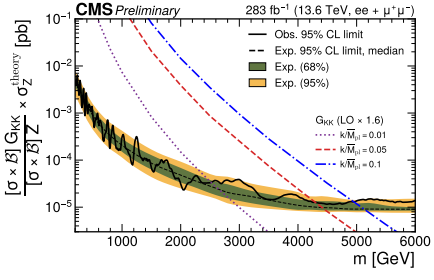
Analysis: Two high-p_T leptons, bump search in sliding mass window of $\pm 4\sigma$ around hypothesized mass or larger, normalizing to SM Z to reduce systematic effects

Results: No significant excess, 95% CL lower mass limits of 5.55 (4.95) TeV are set for Z'_{SSM} (Z'_{ψ})









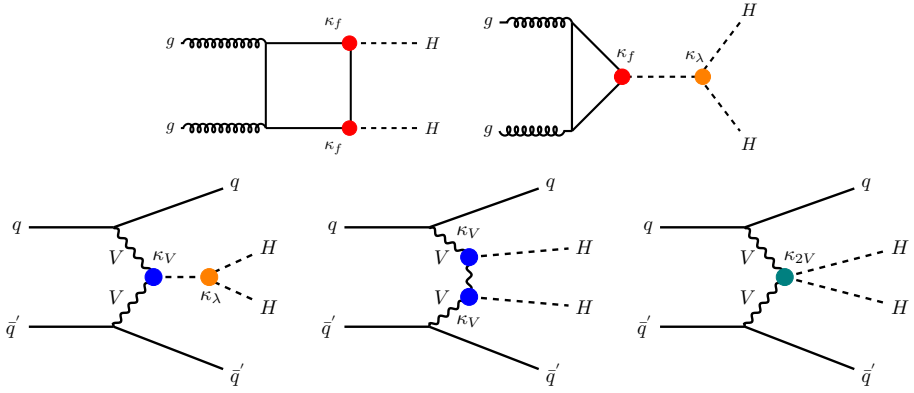
Summary

- **LHC Run 3 Legacy:** Data-taking successfully completed, delivering an outstanding ~ 351 fb^{-1} of pp collision data at $\sqrt{s} = 13.6$ TeV to both experiments. The CERN complex has smoothly transitioned into LS3.
- Many Run 3 results already out, and many more to come (with the full dataset)!
- With continued improvements in analysis techniques and new HL-LHC detectors, we can expect to surpass our own projections
- **Preparing for the next generation of experimental particle physics**

ATLAS CMS

Thank you!

Di-Higgs production

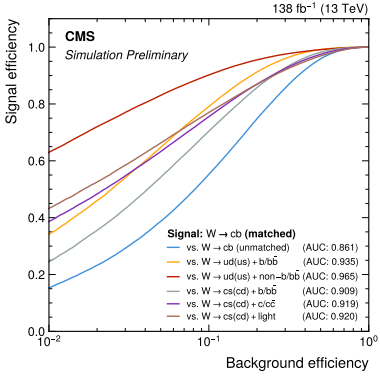


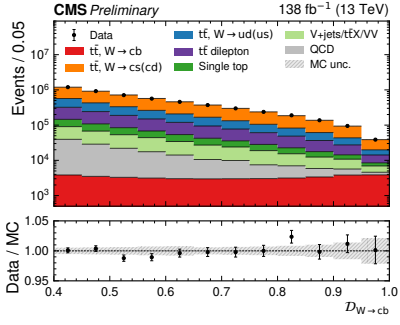
Feynman diagrams that contribute to *ggF* and VBF *HH* production at LO with coupling modifiers affecting the Higgs boson coupling strength to fermions (κ_f), to vector bosons (κ_V), to two vector boson vertices ($\kappa_2 V$), and the Higgs boson self-coupling strength (κ_λ)

$|V_{cb}|$ CKM matrix element in $t\bar{t}$ events

CMS-PAS-TOP-26-001, Run 2

- New $|V_{cb}|$ analysis from CMS
- Use BDT for $t\bar{t}$ kinematic reconstruction, tag hadronically-decaying Ws
- Multiclass DNN to separate $W \to cb$ from other $W \to qq'$(+jets)
- Fit with 2ℓ control region
- Complementary to B-physics measurements; probe at EW scale





$$|V_{cb}| = 4.59^{+0.44}_{-0.48}(\text{stat.})\ ^{+0.64}_{-0.76}(\text{syst.}) \times 10^{-2}$$