Universität Siegen

HEP Experimental High Energy Physics
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ATLAS & CMS: Physics Highlights

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LI - International Meeting on Fundamental Physics
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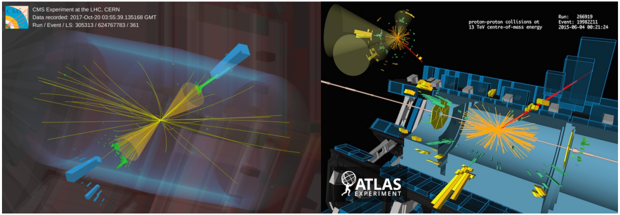


Where do we stand?

- Higgs-like particle with a mass of 125 GeV, properties match the Standard Model (SM) Higgs
    - Not the end but a whole new window of experimental and theoretical possibilities!
- Excellent agreement between very precise measurements of SM processes and predictions (lots of progress on the theory side also!)
- Few anomalies in flavour physics, g-2, etc. but no clear sign that the SM *breaks*
- The SM is not the end of the story! Many open questions!
    - With the *completion* of the SM: No certainty - and no clear indication of the energy scale of new phenomena

The tasks of the ATLAS and CMS experiments

What?

- Study with highest precision what has not yet been scrutinized in depth: Higgs boson, the top quark
- Revisit areas of previous precision experiments with a great deal of scrutiny: Electroweak, QCD, flavour
- Explore the unknown: Extend the scope of searches for new phenomena at high energies: new data-taking strategies, new triggers, new AI applications

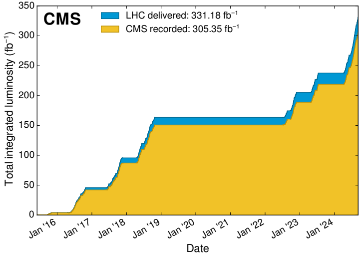
How?

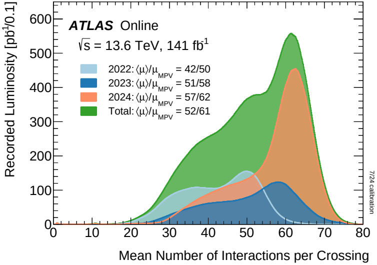
- Exploiting the LHC collisions at the energy frontier (searches at the TeV scale) and the intensity frontier (Higgs and EW precision program)
- Exploting the capabilities of the experiments as flavour experiments (top quark physics + dedicated data streams for b, c, and τ), heavy ion experiments (PbPb and pPb LHC runs) and photon-photon collider experiments (ultra-peripheral heavy ion collisions, proton tagging in pp, ...)

→ Here: just a (tiny) selection of latest results in QCD, EWK, top quark, Higgs and BSM searches!

Where are we now? Run 3 data taking

- First phase of the LHC program to be completed soon
- Reach already the goal of $>300\ \text{fb}^{-1}$ (Run2 + Run3) by the end of 2025!
- Nearly 100 fb^{-1} of delivered proton-proton luminosity at 13.6 TeV this year
- Working on upgrading the detector for the High-Luminosity phase (target is 3000 fb^{-1} by 2041)
- Pushing detectors beyond their limits: Recording up to 63 simultaneous collisions/event (2.5x design, 45% of HL-LHC)

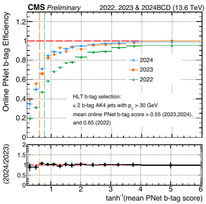


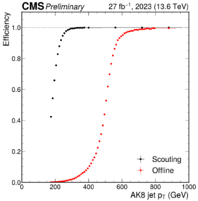


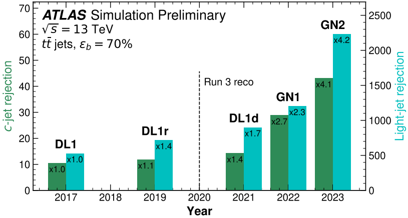
Few words on performance

Improvements in precison, reach of searches driven by improvements in trigger, performance, methods (huge progress thanks to ML)

- New trigger strategies
  - Gain in acceptance with looser ParticleNet b-trigger
  - Lower threshold for large-radius jets with scouting (trigger-level object reconstruction)
- Flavour tagging performance transformed through the use of advanced ML techniques
  - 4x background rejection improvement with graph neural network tagger (GN2) compared to Run 2 in ATLAS
  - Also huge improvements in CMS by using graph-nets and transformers
- ... and many more!

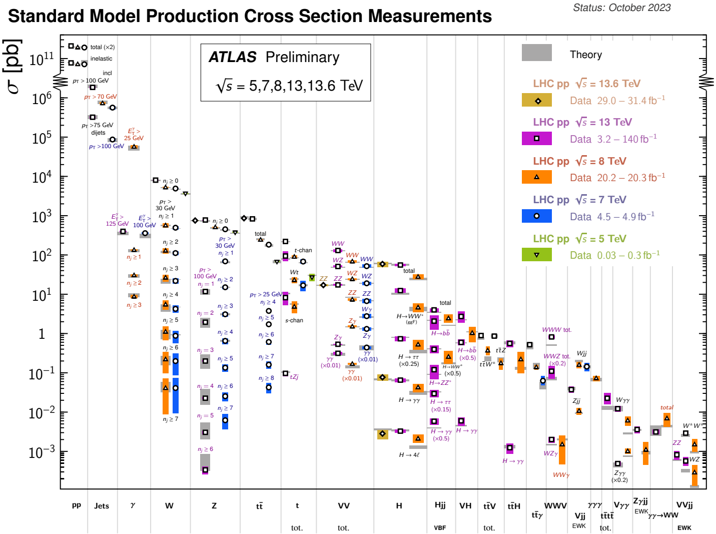






Measurements of SM processes

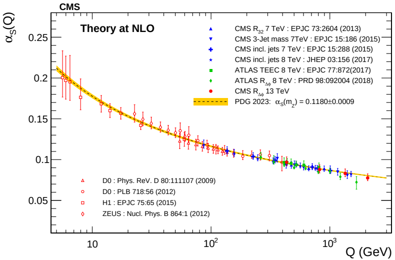
- Scrutinising the SM predictions over O(10) orders of magnitude in cross section
- Increasing precision, observation of rare processes

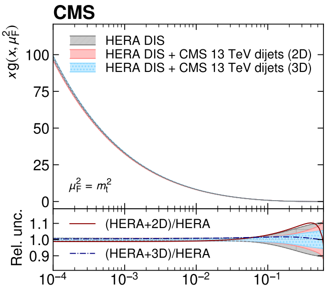


QCD and Electroweak (precision) Physics

Jet physics

- QCD multijet production: dominant high-p_T process at hadron colliders
- Test of QCD at highest available energies in the laboratory
  $\rightarrow$ signs of new physics?
- Sensitive to the strong coupling constant and its running at much higher energy scales than other strategies
- Important inputs to parton distribution function (PDF) fits (high-x gluon PDF)
- Important background at the LHC: many other processes with multijet signatures (top quark, Higgs, ...)

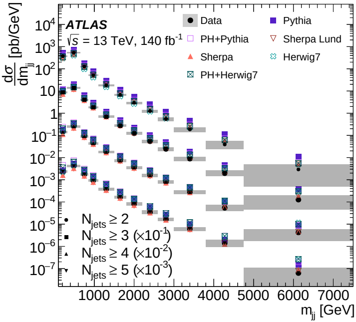


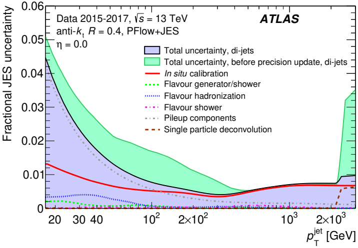


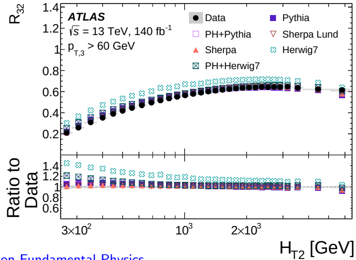
[arXiv:2404.16082, arXiv:2404.16082]

Jet cross-section ratios [arXiv:2405.20206]

- Measure jet cross-section ratios between bins of jet multiplicity
- Double differential: Dijet invariant mass or angular radiation ($< 10\%$ precision)
- Triple differential: scalar sum of p_T of two leading jets, H_{T2} ($<$few %)
- Relies on improved JES uncertainty ($< 1\%$)







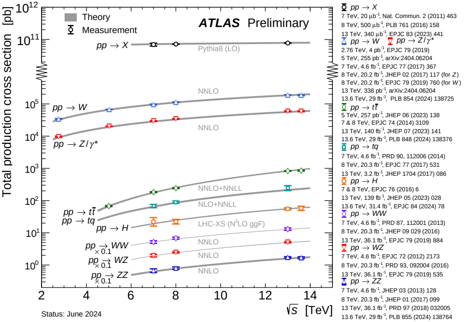
Testing the Electroweak sector

Rich variety of electroweak interaction derived from symmetry principles
$SU(2)_L \times U(1)_Y \rightarrow W^{\pm}, Z, \gamma$

- Mass of electroweak gauge bosons and interaction strength predicted precisely from g, g', v, λ

$$\rho = \frac{m_W^2}{m_Z^2 \cos^2 \theta_W}$$

- Testing the EWK theory
  - Precision measurements of single W/Z bosons
  - At high energy in multiboson production



[ATL-PHYS-PUB-2024-011]

Testing the Electroweak sector

The precision frontier

- Radiative corrections modify propagators and decay vertices

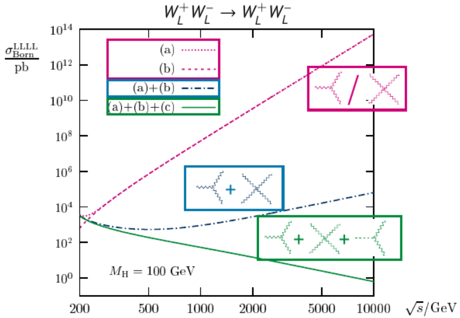
$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta)$$

$$\sin^2\theta_W \rightarrow \kappa_f \sin^2\theta_W = \sin^2\theta_{eff}^f$$

- Sensitivity to a wide range of physics through quantum loops

The energy frontier

- Tests of the electroweak theory through gauge cancellations at high energy
- Deviations can lead to potentially large effects



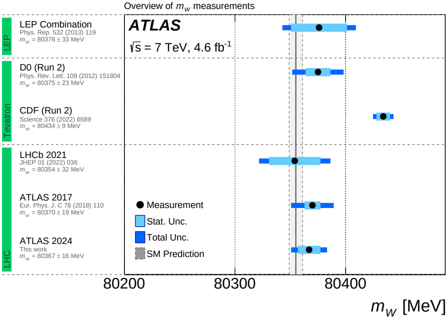
from Nucl. Phys. B525 (1998) 27-50

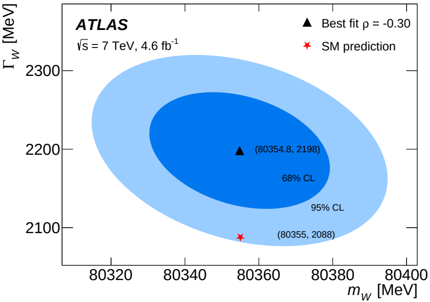
W-boson properties [arXiv:2403.15085]

- First measurement of the W width at the LHC, together with an improved W mass using 7 TeV data
- Improved method: profile-likelihood fit of m_T and p_T^ℓ using $W \to \ell\nu$ events

- $m_W = 80366.5 \pm 15.9$ MeV
  (CT18 parton distribution functions)
- Largest systematic uncertainties: calibration, the theoretical modeling and the PDFs

- From simultaneous measurement $m_W = 80354.8 \pm 16.1$ MeV and $\Gamma_W = 2198 \pm 49$ MeV

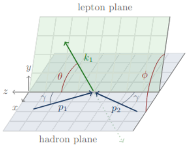


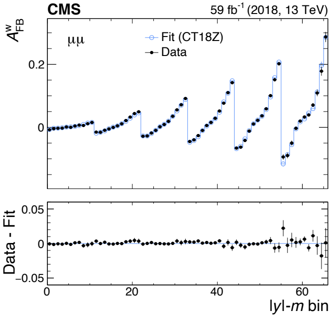


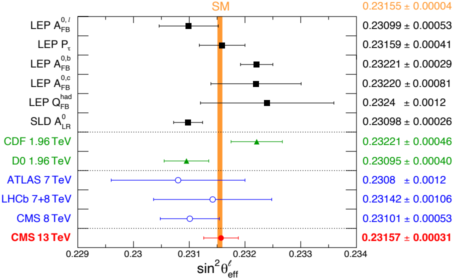
$Z/\gamma^* \to \ell\ell$ and the weak mixing angle [arXiv:2408.07622]

- $\sin^2\theta^{\ell}_{eff}$ extracted from $pp \to \ell\ell$ forward-backward (A_{FB}) asymmetry at 13 TeV

$$\frac{d\sigma}{d\cos\theta} \sim 1 + \cos^2\theta + \frac{1}{2}A_0(1 - 3\cos^2\theta) + A_4\cos\theta$$



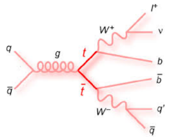




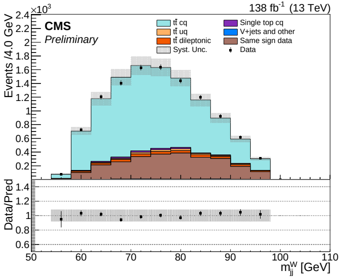
- Measured in bins of $y(\ell\ell)$ and $m(\ell\ell)$
- Sensitivity enhanced with extended acceptance for forward electrons
- Matches LEP/SLD precision
- Compatible with the SM precision

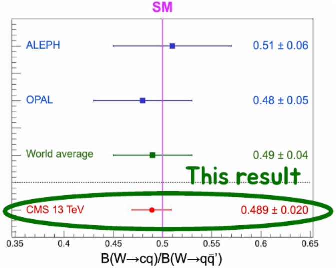
W-boson hadronic decay branching fractions [CMS-PAS-SMP-24-009]

- $R_c^W = \mathcal{B}(W \to cq)/\mathcal{B}(W \to q\bar{q}')$ from top quark pair ($t\bar{t}$) events in single-lepton final states



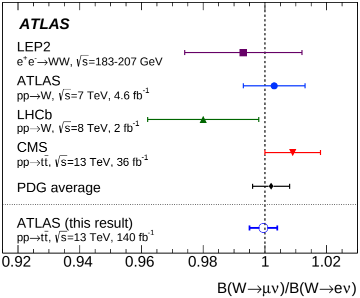
  - Jets tagged as originating from the hadronization of c quarks by the presence of a muon inside the jet → dedicated $c \to X\mu\tau$ tagger
- $R_c^W = 0.498 \pm 0.005(\text{stat}) \pm 0.019(\text{syst})$
  - Most precise measurement (4%)
  - Dominant systematic uncertainty: charm tagging efficiency
- Also measured $|V_{cs}| = 0.959 \pm 0.021$



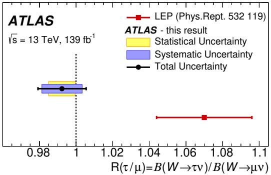


Lepton flavour universality in W-boson decays [arXiv:2403.02133]

- Universality of the coupling of $\ell^{\pm}$ to W boson is a fundamental property of the SM
- Exploits clear selection of W boson in $t\bar{t}$ pairs
- Tested via $R(\mu/e) = B(W \to \mu\nu)/B(W \to e\nu)$
- $R(\mu/e) = 0.99995 \pm 0.0045$ - higher precision than current world average!



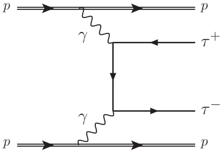
- Complements $W \to \tau\nu$ results [e.g Nature Phys. 17 (2021) 7, 813-818]: Some disagreement (2.7σ) of the on-shell $W \to \tau\nu$ results seen at LEP, but excellent agreement with LHC measurements

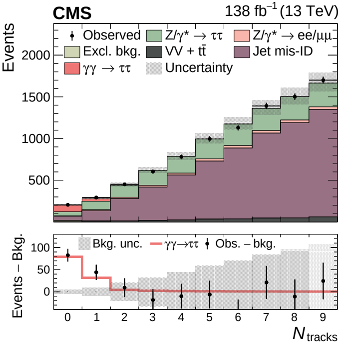


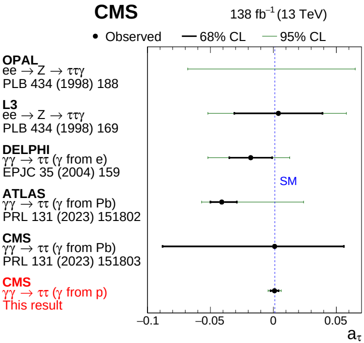
Production of τ-leptons from photons [arXiv:2406.03975]

Observed $\gamma\gamma \to \tau\tau$ production in pp collisions, for the first time

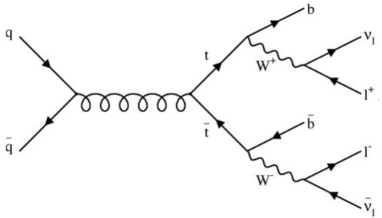
- Constrain anomalous magnetic and electric dipole moments: Probed τ g-2 with unprecedented precision





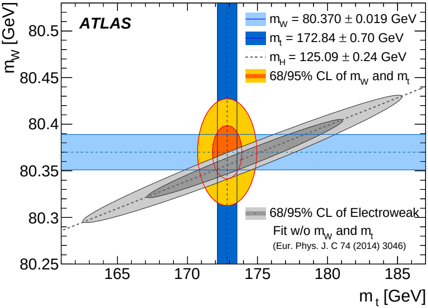


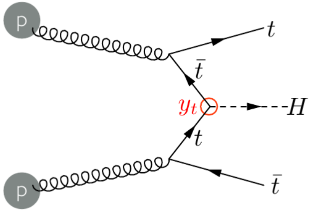
Top quark Physics



Top quark physics

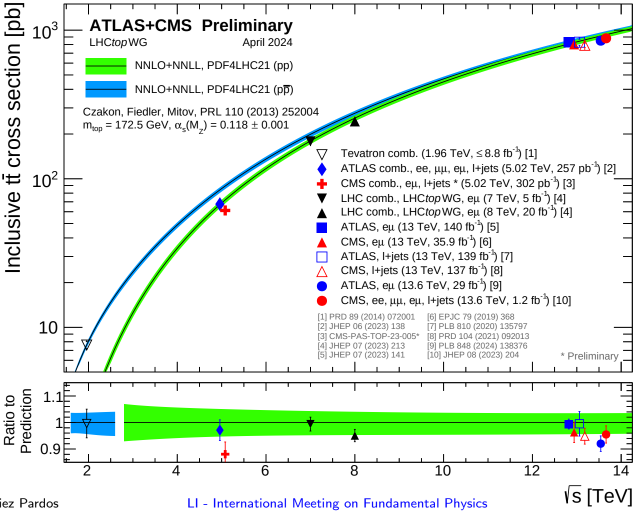
- Most massive elementary particle known
- Short-lived, decays before hadronizing, allows studying the properties of a bare quark
- Precision tests of perturbative QCD (α_s, PDFs, m_t)
- Other properties: spin correlations, couplings, asymmetries predicted by the SM
- Essential to study Higgs properties, measure top Yukawa coupling
- Potential portal to New Physics: Production & decay sensitive to anomalous couplings, charged lepton flavour and baryon number violation, CP violation, flavour changing neutral currents...





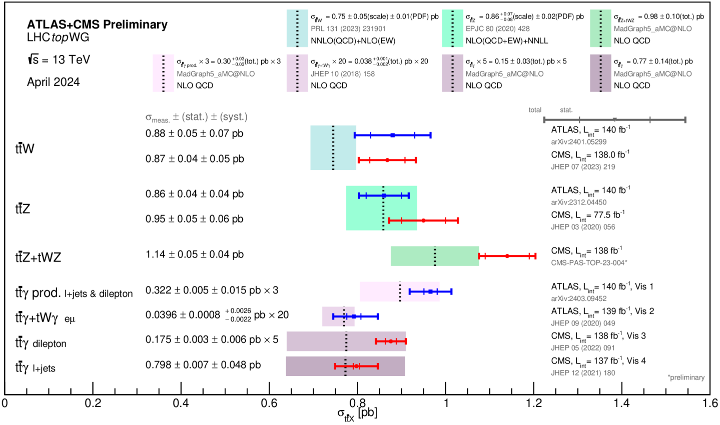
Top quark cross sections

- All decay channels and centre-of-mass energies
- Stringent tests of pQCD via inclusive and differential cross sections

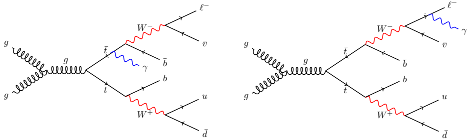


Top quark + X

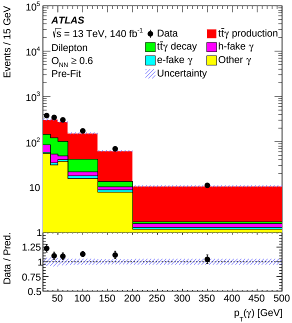
- Evidence for rare(r) processes such as tWZ
- Moving towards combined measurements $t\bar{t}Z + tWZ$
- Detailed studies of less rare processes such as $t\bar{t}\gamma$

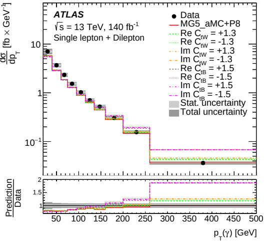


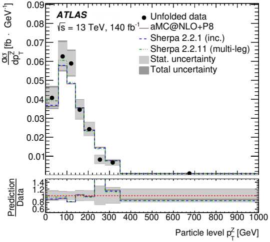
Associated top quark pair production ($t\bar{t}\gamma$) [arXiv:2403.09452]

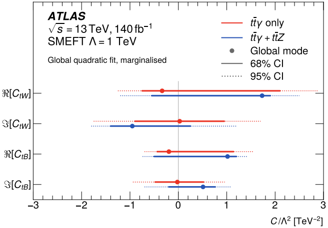


- Radiative production: probe structure of $t\gamma$ coupling
- NN to enhance separation between photons from production and decay
- Sensitive to top quark anomalous dipole moments, EFT interpretations (dim-6 operators - CtW, CtB)



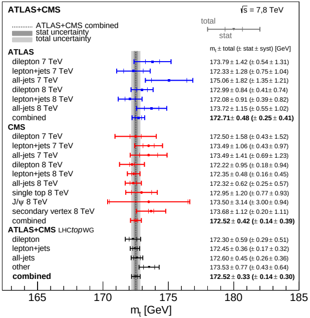






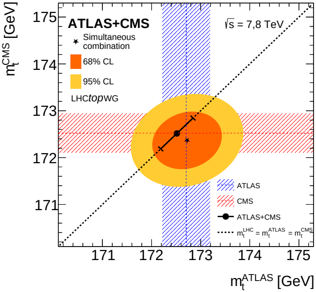
Top quark mass

- Indirect measurements from cross section: $\sim$ 1% precision (clear interpretation)
- Direct measurements from top quark decays: better precision
  - Mass from boosted top-jet: Future prospects in precision & theoretical interpretability
  - Alternative measurements: sensitive to different systematics



Run-1 top quark mass combination [arXiv:2402.08713]

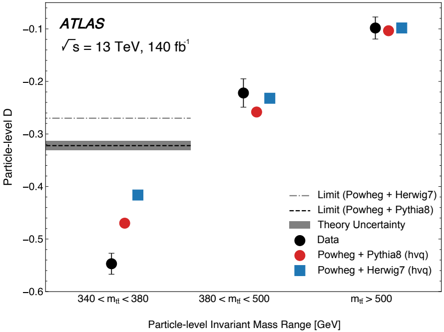
- Combination of 15 input measurements (6 ATLAS + 9 CMS)
- Detailed study of correlations
- Consistency checks among measurements

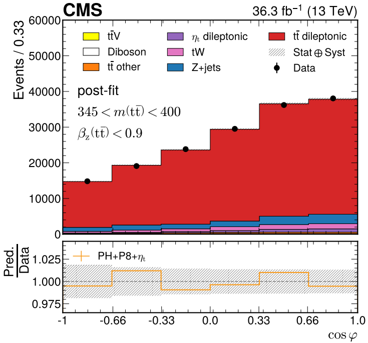


Observation of top quark entanglement [arXiv:2406.03976,arXiv:2311.07288]

- Sufficient condition for entanglement from spin correlation matrix
  - Using diagonal elements: $\Delta = C_{33} + |C_{11} + C_{22}| > 1$
  - Entanglement proxy $D = -\Delta/3 = -Tr[C]/3$ (for small $m_{t\bar{t}}$) can be extracted from angle between decay products
    $\frac{1}{\sigma}\frac{d\sigma}{d\cos\phi} = \frac{1}{2}(1 - D\cos\phi)$

$\rightarrow$ $D < -1/3$ established at 5σ level

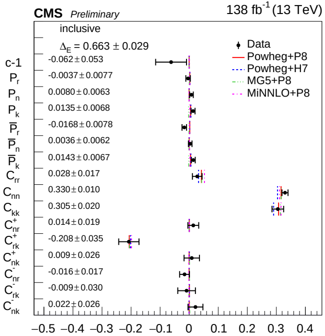


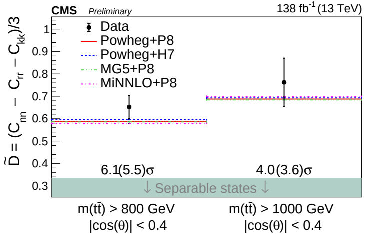


Taking it a step further [CMS-PAS-TOP-23-007]

- Measuring the correlation matrix in single-lepton $t\bar{t}$ events
- All coefficients of polarization vectors and correlation matrix from fit to the angles of two decay products
- Using NN to reconstruct the $t\bar{t}$ system
- Δ from the full matrix, or from two proxies: D and $\tilde{D} = 3(C_{33} - C_{11} - C_{22})$ for high masses

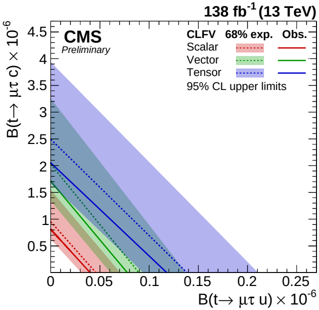
- Higher $m_{t\bar{t}}$ reach - why is it relevant?
  - Large fraction of events with space-like separation
  - Prospects for Bell inequality tests

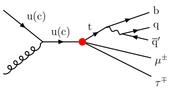


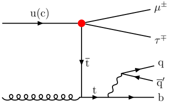


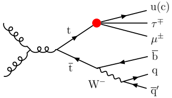
Charged-lepton-flavour violation (cLFV) [CMS-PAS-TOP-22-011]

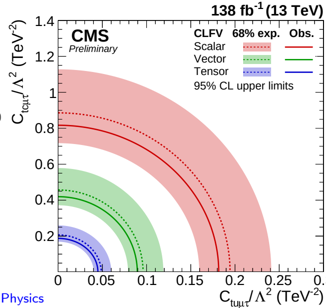
- Lepton flavour conservation arises due to an accidental symmetry of the SM
- Violation possible in the SM via neutrino mixing at loop level ($BR(\mu \to e\gamma) < 10^{-55}$!)
- cLFV featured in several BSM models (leptoquarks, SUSY, 2HDM) and interpreted in terms of EFT
- Searches for $e\mu tq$ and $\tau\mu tq$ vertices, both in production and decay



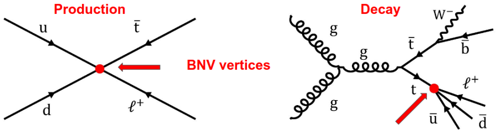


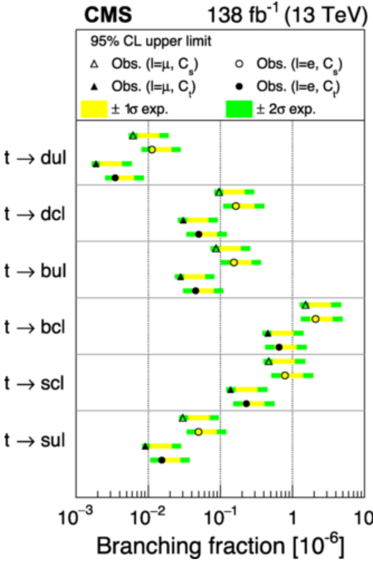






Baryon number violation (BNV) [PRL 132 (2024) 241802]



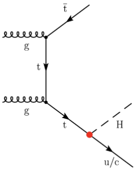


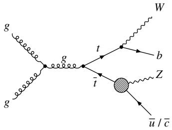
- Search for BNV interactions in top quark production (first time) and decay
- Selection: two oppositely-charged leptons (e, μ), exactly one b-tagged jet and high missing transverse momentum
- Upper limits on the strength of the BNV couplings and translated to limits on the BRs for the BNV top quark decays

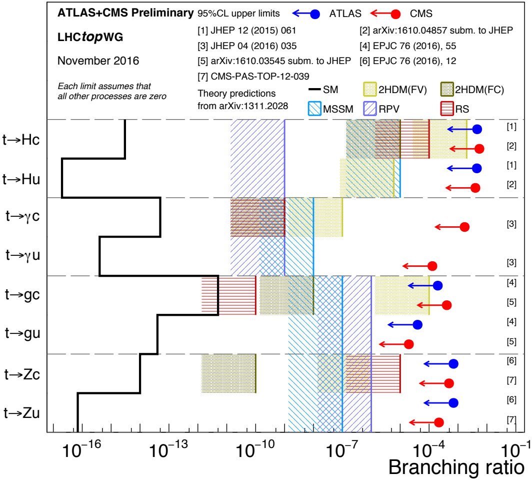
Searches for Flavour Changing Neutral Currents over time

Top quark couples to up-type quark (u or c) and neutral boson (γ, Z, H, g)

- Forbidden at tree-level in SM
- Heavily suppressed at higher orders via GIM suppression
- BSM can enhance FCNC BRs up to $\sim 10^{-4}$
- Any observation of FCNC can indicate new physics!







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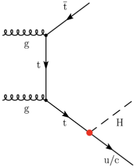

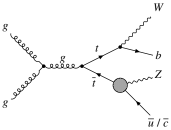

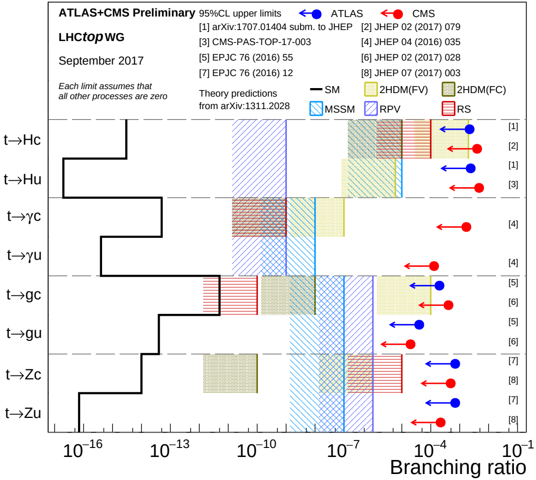

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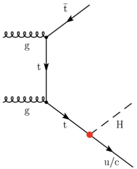

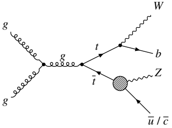

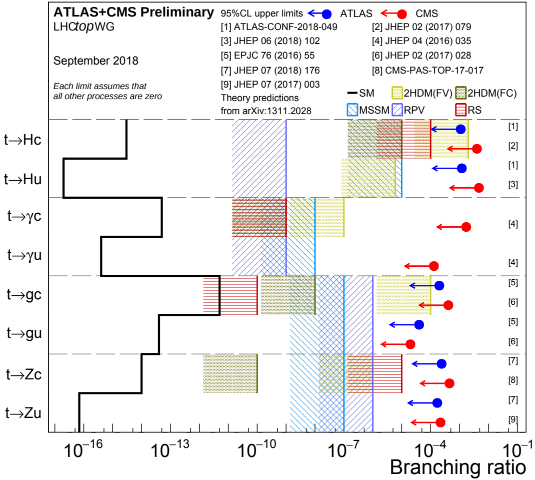

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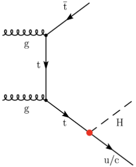

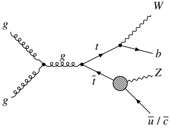

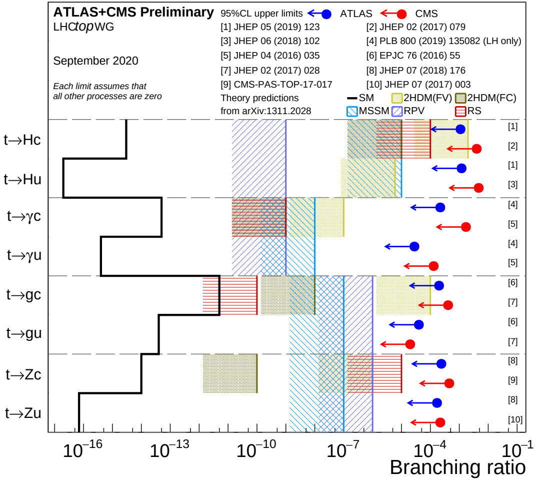

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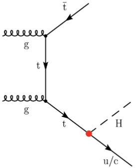

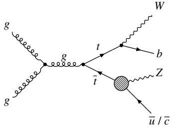

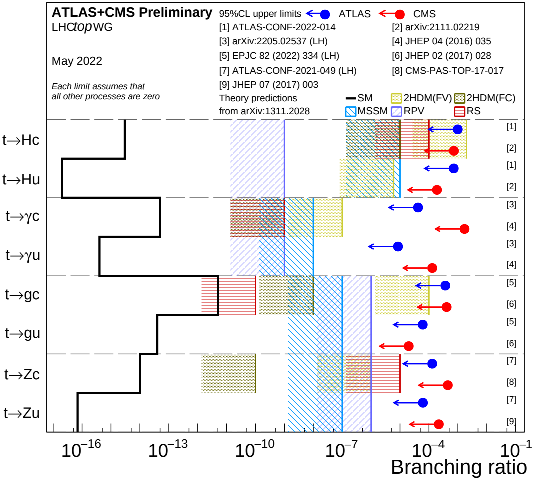

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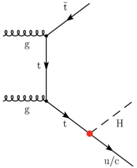

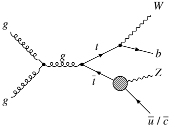

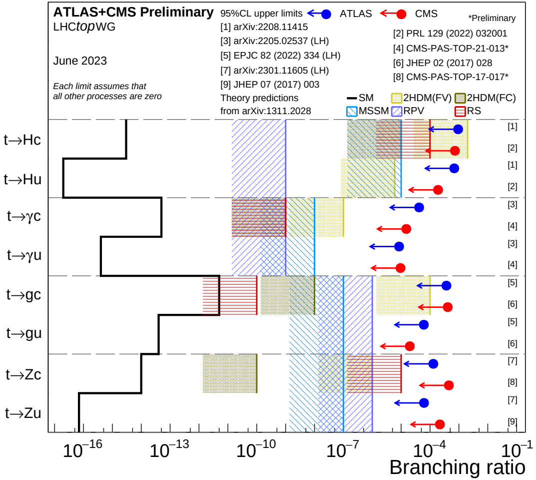

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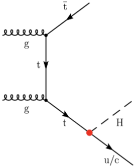

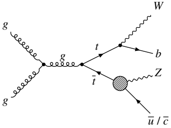

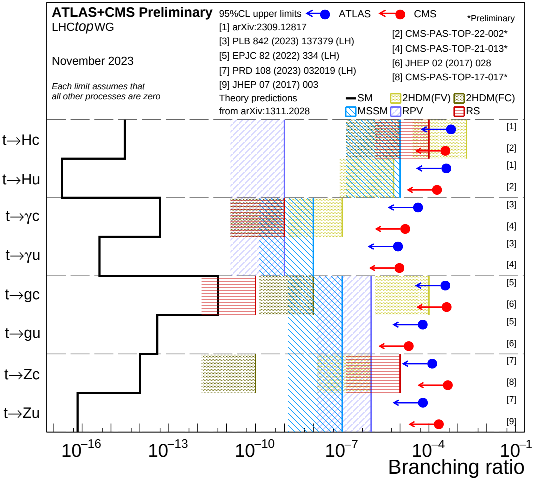

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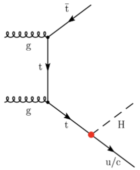
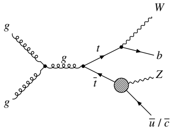
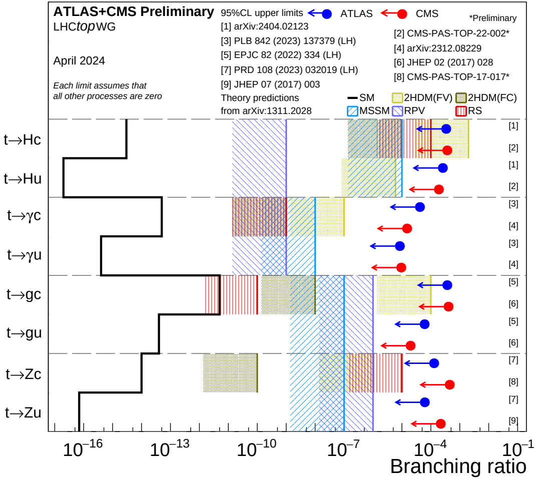
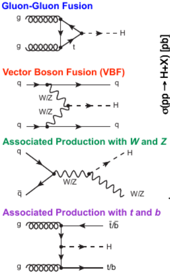


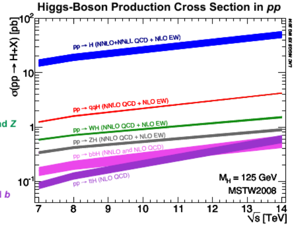




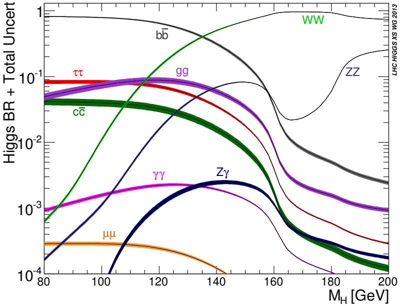
No signs of flavour physics associated to top quarks, approaching sensitivity to BSM

The Higgs sector



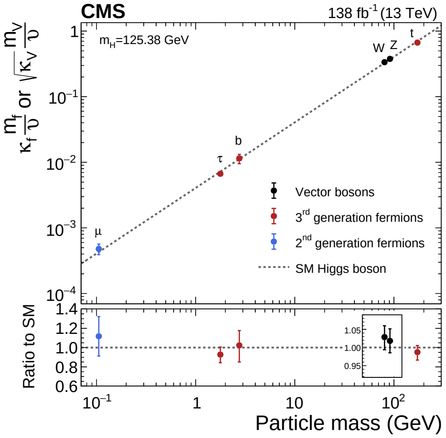


https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGCrossSectionsFigures



The SM Higgs boson: status

- Mass from Run 1+2 ATLAS combination: $m_H = 125.11 \pm 0.11$ GeV (syst: 0.09 GeV)
- Indirect Higgs width from offshell: $\Gamma_H = 4.6^{+2.6}_{-2.5}$ MeV
- Probe couplings by measuring accessible production and decay modes
- Ongoing studies include:
  - Detailed kinematic studies of observed modes
  - Searches for rarer production/decay modes (bbH, tH, cc and $\mu\mu$)
  - Higgs self-couplings

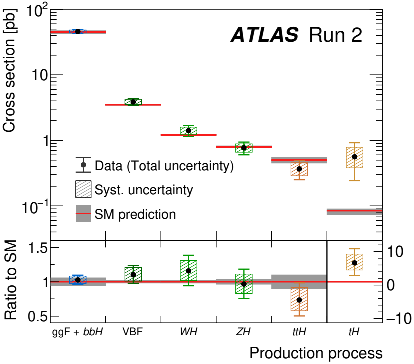


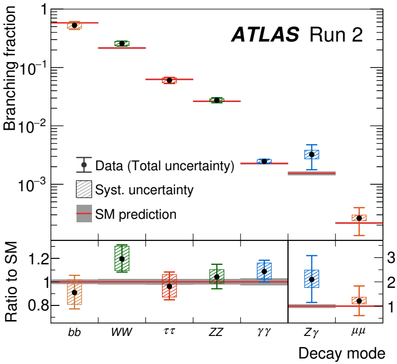
Nature 607 (2022) 60-68, Nature 607, 52-59 (2022)

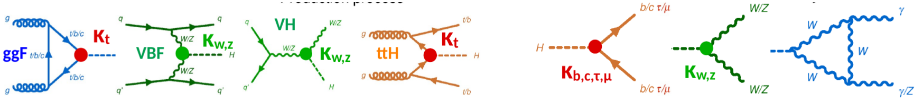
SM Higgs boson production and decay

[Nature 607 (2022) 60-68, Nature 607, 52-59 (2022)]

- Main production and decay processes observed, measured with better precision than 10-20%

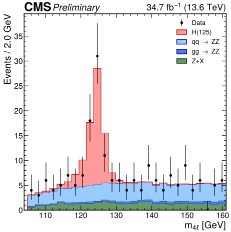


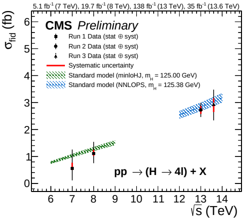


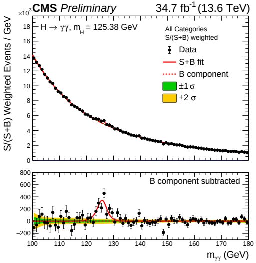


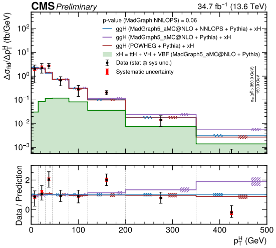
Higgs bosons at 13.6 TeV [CMS-PAS-HIG-24-013, CMS-PAS-HIG-23-014]

- Inclusive/differential measurements in $H \to \gamma\gamma$ and $H \to ZZ$
- Using data from 2022: measurements statistically limited









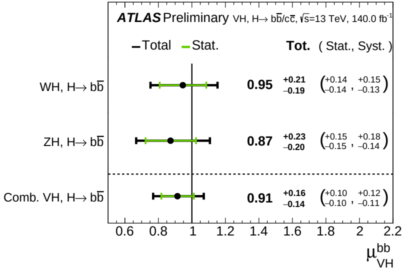
Open questions where the Higgs boson can help

- What is the origin of quark and lepton masses?
  - Fermion flavour violating Higgs boson decays
  - Are there modified Higgs couplings to other particles
- Why is the EW interaction much stronger than gravity?
  - Are there anomalies in interactons with W, Z bosons?
  - New particles at the TeV scale
  - Is the Higgs boson elementary?
- What is dark matter?
  - Can the Higgs boson provide a portal to dark matter?
  - New decay modes of the Higgs boson?
  - Higgs lifetime consistent with the SM?
- Why is there more matter than antimatter?
  - Higgs boson self-coupling: strong first-order Electroweak Phase Transition?
  - Are there multiple Higgs sectors?
  - Are there CP-violating Higgs boson decays

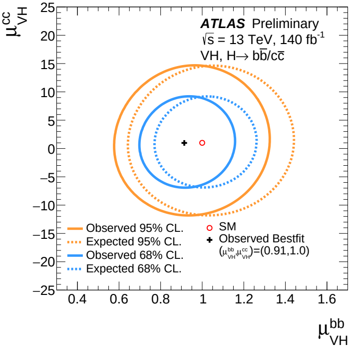
From N. Berger, ICHEP2024 based on G. Salam et al, Nature 607, 41-47 (2022)

Precision Higgs - VH to bb/cc [ATLAS-CONF-2024-010]

- $H \to bb$: largest Higgs BR (58%)
- $H \to cc$: largest BR to 2nd gen. fermions (2.9%)
- Require b-jets or c-jets, split signal in $N_\ell = 0$ ($Z \to \nu\nu$), 1 ($W \to \ell\nu$) or 2 ($Z \to \ell\ell$)
- Cross-check analysis: observation of $VZ(bb)$, $VZ(cc)$



First observation of $WH \to bb$ (5.3σ)

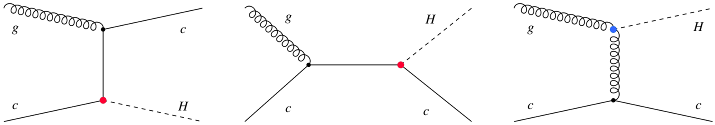


$\mu_{VH\to cc} < 11.3$ 95% CL (10.4 exp.)

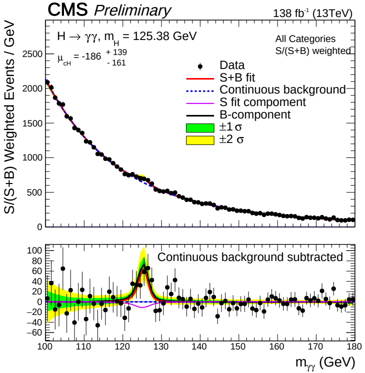
Best limit to date

CMS Results with similar sensitivity PRD 109 (2024) 092011

Search for $pp \to H(\to \gamma\gamma) + c$ production [CMS-PAS-HIG-23-010]



- Potential to constrain κ_c, also large contributions from non-κ_c-dependent diagrams
- Large backgrounds: focus on $H \to \gamma\gamma$ decay
- $\sigma(cH) \sim 90$ fb$\times$BR$(H \to \gamma\gamma) \sim 0.2\% \to 0.2$ fb
- κ_c-dependent part: $\mu_{cH} < 243$ (355), $|\kappa_c| < 38.1$ (72.5) at 95% CL
- Also new ATLAS measurement, target inclusive $H + c$: $\sigma(H + c) = 5.2 \pm 3.0$ pb (SM: 2.9 pb), < 10.4 pb at 95% CL [arXiv:2407.15550]



Higgs width from $t\bar{t}t\bar{t}$ + on-shell Higgs [arXiv:2407.10631]

On-shell Higgs
Integrate out the mass

$$\sigma \propto \frac{g_i^2 g_f^2}{m_H \Gamma}$$

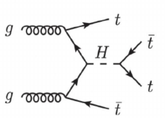
$$\frac{d\sigma}{dm^2} = \frac{g_i^2 g_f^2}{(m^2 - m_H^2)^2 + m_H^2 \Gamma^2}$$

Off-shell Higgs

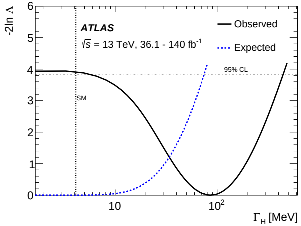
$$(m^2 - m_H^2)^2 \gg m_H^2 \Gamma^2$$

$$\frac{d\sigma}{dm^2} = \frac{g_i^2 g_f^2}{(m^2 - m_H^2)^2}$$

- Higgs couplings from on-shell cross-sections and BRs: assume SM Higgs width (4.1 MeV) or an SM-like dependence
- Processes like $t\bar{t}t\bar{t}$ with an off-shell Higgs have negligible width dependence: width-free determination of couplings



→ Combined on- and off-shell measurements: constraint on the Higgs width (Nature 607, 52-59 (2022) + EPJC 83 (2023) 496, EPJC 84 (2024) 156)



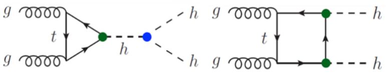
Assuming loop-induced coupling modifiers are parametrized independently of tree level ones (minimal model dependence)

Higgs boson pair production at the LHC

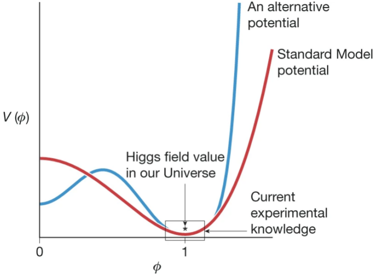
HH production to directly probe Higgs self-coupling and hence electroweak symmetry breaking (EWSB) mechanism

- Access to shape of the Higgs potential

$$\mathcal{L} \supset -\lambda v^2 H^2 + \lambda v H^3 - \frac{1}{4}\lambda H^4 = \frac{1}{2} m_H H^2 + \boxed{\frac{m_H^2}{2v} H^3} - \frac{m_H^2}{8v^2} H^4$$



  - Very small SM cross-section due to destructive interference with diagrams with Yukawa coupling: $\sigma_{SM}(HH) = 33.5$ fb at 13 TeV →1000 smaller than $pp \rightarrow H$



Nature 607, 41-47 (2022)

- Also accesses other interactions, e.g. VVHH (κ_{2V})

See new result: CMS-PAS-HIG-24-001

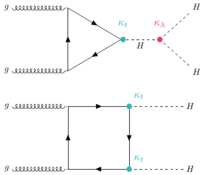
Higgs boson self-coupling [arXiv:2406.09971]

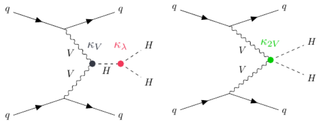
- Focusing on the two major production modes: gluon-gluon fusion (ggF) and vector boson fusion (VBF)
- Combine $HH \rightarrow bb\tau\tau + bb\gamma\gamma + bbbb + multileptons + bb\ell\ell + \not{E}_T$:

	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%

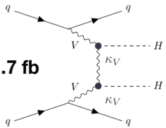
  - Using cut-based and multivariate techniques

ggF: 31 fb





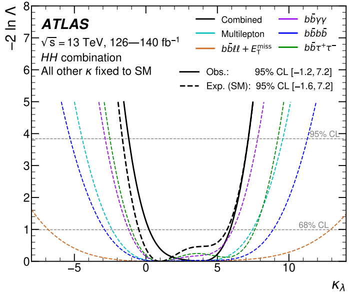
VBF: 1.7 fb

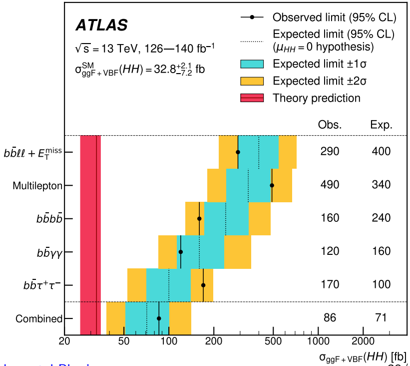


Higgs boson self-coupling: Results [arXiv:2406.09971]

- Close to within 1σ of the SM
  - $\mu_{HH} < 2.9$ (obs) and 2.4 (exp) at 95% CL
  - Sensitivity dominated by ggF mode
  - Also Effective field theory interpretation to probe low energy dynamics of EWSB with 3 Wilson coefficients

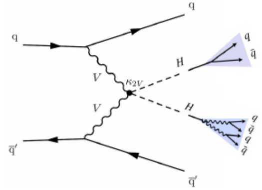
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%



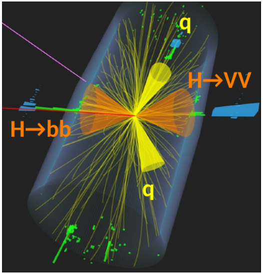


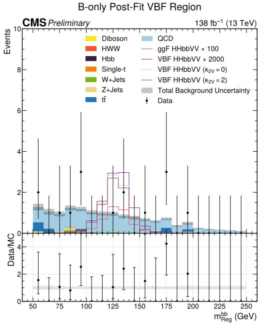
Search for $HH \to b\bar{b}VV$ [CMS-PAS-HIG-23-012]

- Search for $HH \to b\bar{b}VV$ production in fully hadronic final states (unexplored before)
- Boosted regime: merged large-radius jets

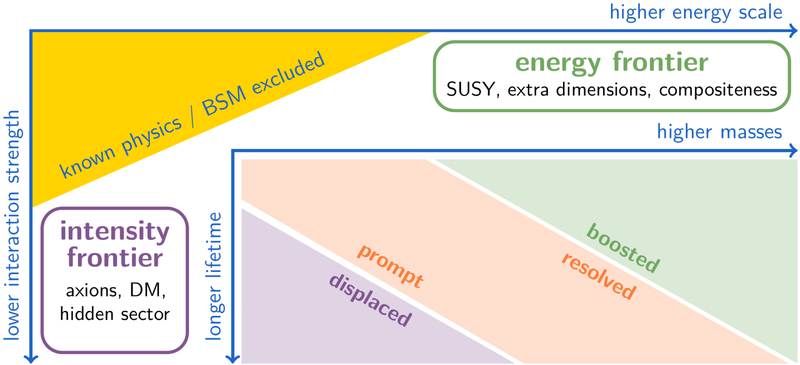


- Use $H \to b\bar{b}$ and new $H \to VV \to q\bar{q}q\bar{q}$ taggers
- $\mu_{HH} < 142$ (69 exp.) and $-0.04 < \kappa_{2V} < 2.05$ at 95% CL
- ATLAS: search in VBF $HH \to b\bar{b}b\bar{b}$, $0.55 < \kappa_{2V} < 1.49$ at 95% CL [arXiv:2404.17193]





Searches

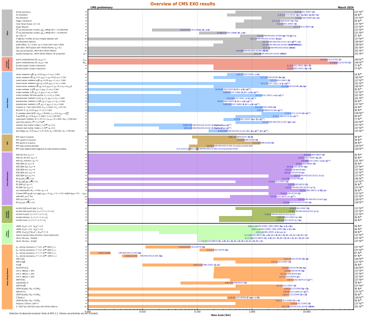


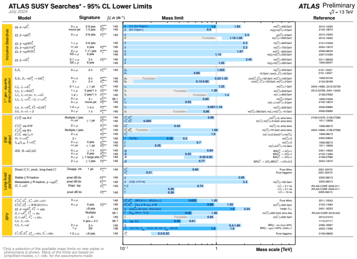
* Courtesy of J. Knolle (LHCP2024)

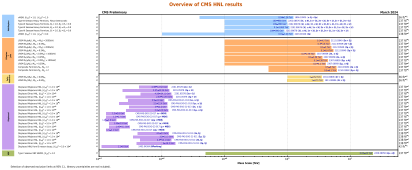
LHC experiments search strategies

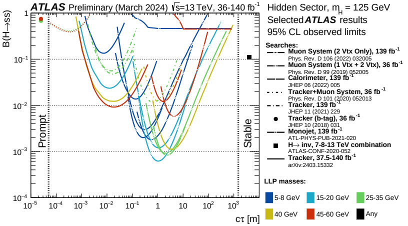
- Precision measurements & searches for rare process and unconventional final states
  - No BSM evidence yet: sensitivity on a wide range of phase space established
- Gain in luminosity and improvements in detector technology enhance potential for discoveries during Run 3
  - Probing various scenarios: Dark Sector, exotic signatures, heavy particles
  - Exploiting standard and exotic signatures: Boosted jets, disappearing jets, emerging jets (with AI taggers), showers in muon detector, etc
  - Data scouting / trigger analysis level allows to extend reach in the low masses regime (heavy neutral leptons, long-lived light particles...)

In pictures: Search for BSM processes



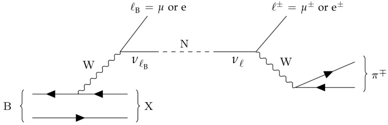




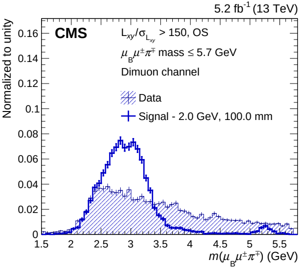


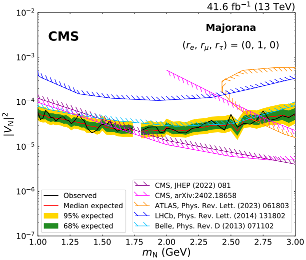
Search for long-lived heavy neutrinos [JHEP 06 (2024) 183]

- Search for HNLs in B decays
- Based on the special data stream recorded in 2018, designed to collect $O(10^{10})$ $b\bar{b}$ events



- Parametric NN for optimal signal/background separation to different HNL masses
- Limits set in Dirac and Majorana scenarios

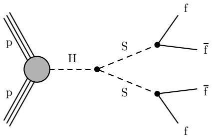


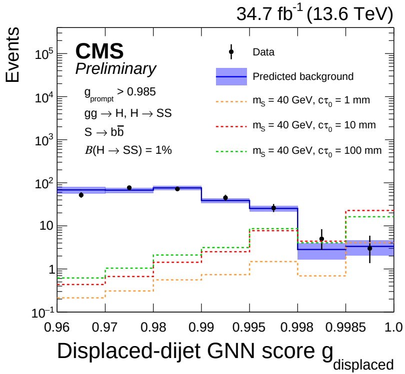


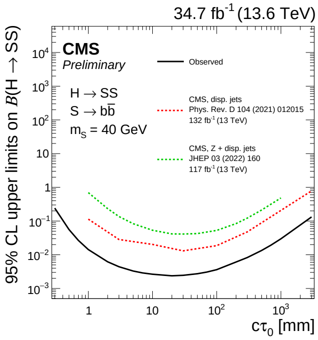
Strongest limits on sum of squares of light-heavy mixing amplitudes from a collider for $1\ \text{GeV} < m_N < 1.7\ \text{GeV}$

Resonances decaying to displaced jets [CMS-PAS-EXO-23-013]

- Search for displaced jets with Run 3 data (2022)
- Model: Higgs boson decay to two long-lived neutral scalars
- Sensitivity significantly improved thanks to
    - displaced vertex reconstruction
    - novel displaced dijet identification based on graph NNs



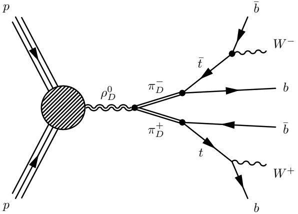




New limits: improved sensitivity with respect to Run 2 with 1/4 of the luminosity!

Dark mesons decaying to top and bottom quarks [arXiv:2405.20061]

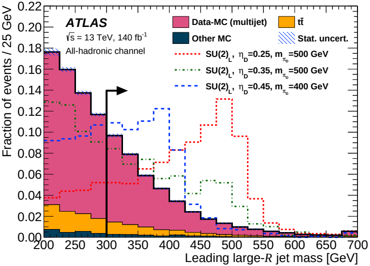
- Dark pseudoscalar π_D and vector ρ_D mesons in stealth dark matter model

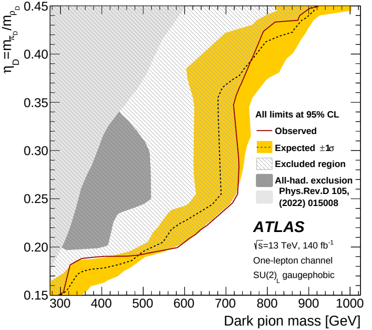


- πD pair production in $t\bar{t}b\bar{b}$ and $t\bar{t}t\bar{b}$ final states

  $300 < m(\pi_D) < 1200$ GeV,
  $0.15 < m(\pi_D)/m(\rho_D) < 0.45$

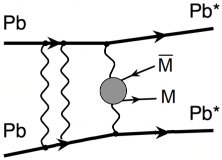
- Using large-radious reclustered jets



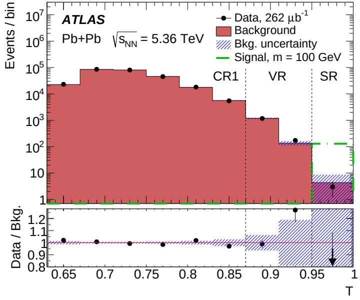


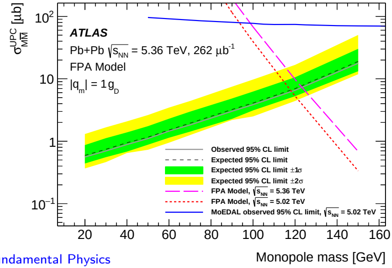
Magnetic monopole pair production [arXiv:2408.11035]

- Search for magnetic monopole pair production as highly ionizing particles in ultraperipheral Pb+Pb collisions



- New data from 2023 with new triggers $\rightarrow$ Up to x8 improvement at masses below 120 GeV





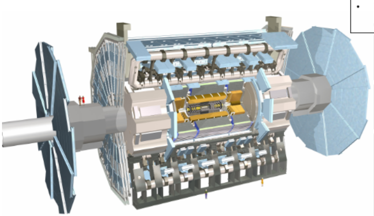
Summary and outlook

- Well into Run 3 with very efficient data taking in 2024, excellent performance
- Improvements in operations and performance play a key role to fully exploit the potential of the LHC data
- Entering the era of precision measurements
    - Several results on EWK physics now competitive with those from e^+e^-
    - Investigating subtle effects as in $t\bar{t}$ spin correlations
- Continue to search for physics beyond the SM
    - Exploring new areas of phase space
    - Exploiting novel performance and analysis techniques
- In parallel, good progress with HL-LHC upgrades transitioning into production mode

BACK UP

This is just the beginning

- Phase-II upgrade activities continually progress into production
- The phase of testing, integration, and planning for the installation is starting



Forward detector
- Upgrade Luminosity Detector (LUCID) and Zero Degree Calorimeter (ZDC) to cope with the higher rate environment (detailed discussion in poster session)

Upgrade of Trigger and DAQ
- L0 trigger at 1 MHz with 10 μs latency, 10 kHz Event Filter output

Upgrade of Calorimeter
- Electronics upgrade for LAr and Tile calorimeters

New High Granularity Timing Detector (HGTD)
- Additional pileup suppression with timing information
- Forward region ($2.4 < |\eta| < 4.0$)
- Low-Gain Avalanche Detectors (LGAD) with 30ps time resolution
- Contributions to luminosity measurement

Upgrade of Muon system
- Additional trigger layers of RPC and replacement of MDT with sMDT in barrel inner station
- Additional TGC layers in endcap inner station
- Upgrade trigger/readout electronics

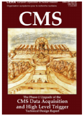
New Inner Tracking Detector (ITk)
- Full silicon tracker covering up to eta = 4 with at least 9 layers on individual tracks
- Less material, finer segmentation

* From Y. Okumura, ICHEP2024

This is just the beginning

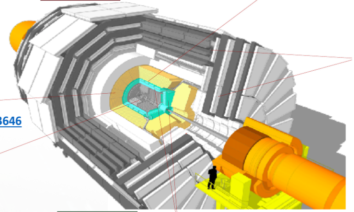
- Phase-II upgrade activities continually progress into production
- The phase of testing, integration, and planning for the installation is starting

L1-Trigger
https://cds.cern.ch/record/2714892
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger
https://cds.cern.ch/record/2759072
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

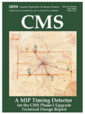
Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η ≃ 3

Calorimeter Endcap
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

Tracker
https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to η ≃ 3.8



MIP Timing Detector
https://cds.cern.ch/record/2667167

Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Beam Radiation Instr. and Luminosity
http://cds.cern.ch/record/2759074
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors

Credits and more information

- Latest CMS results: https://cms.cern/news/cms-ichep-2024
- ATLAS results: https://atlas.cern/tags/physics-results
- Nice ATLAS and CMS overview talks at the LHCP24 and ICHEP24 conferences:

  M. Pierini, M. Dunford, W. Adams, H. Gray, N. Berger, P. Sommer, etc.

Precision Higgs - VH to bb/cc [ATLAS-CONF-2024-010]