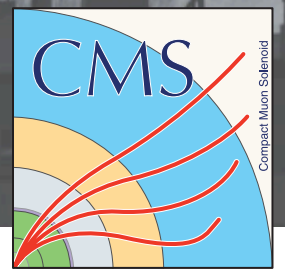
CMS Overview

Milos Dordevic on behalf of the CMS Collaboration

Vinca Institute of Nuclear Sciences, National Institute

of the Republic of Serbia, University of Belgrade







UNIVERSITY OF BELGRADE

13 – 17 November 2026, Bratislava, Slovakia

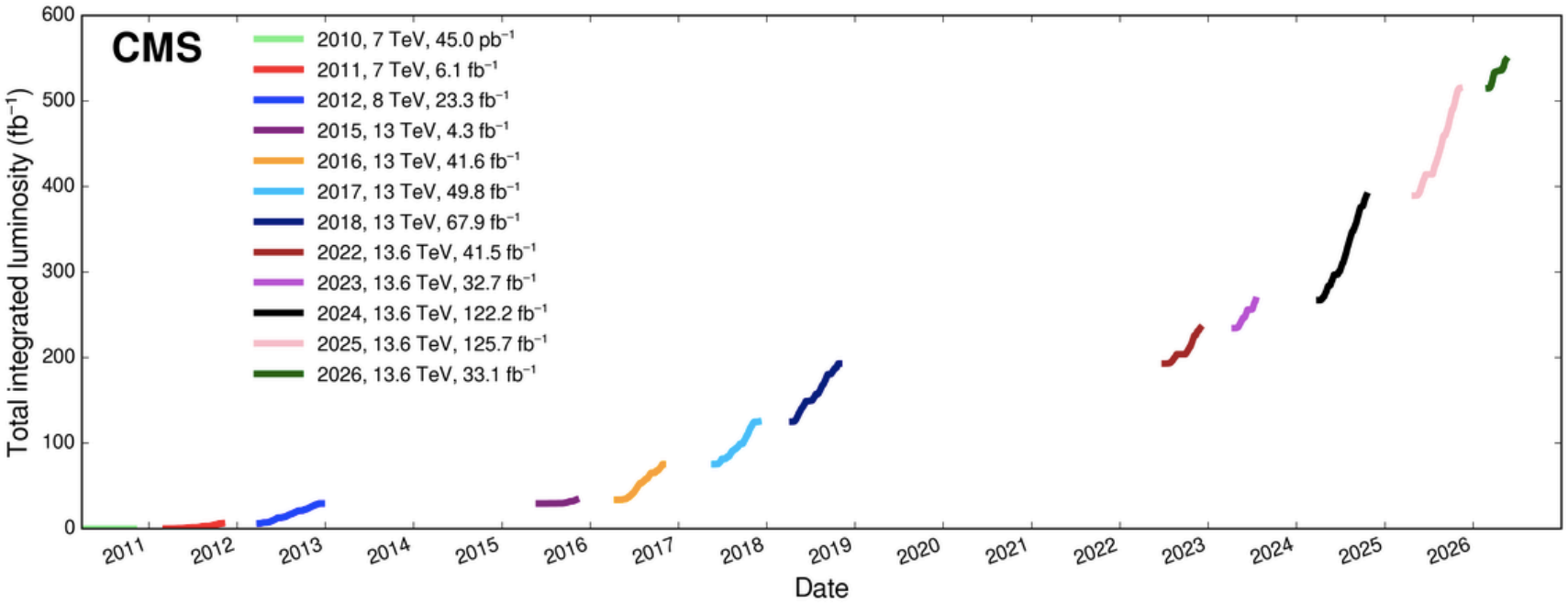
Outline of the talk

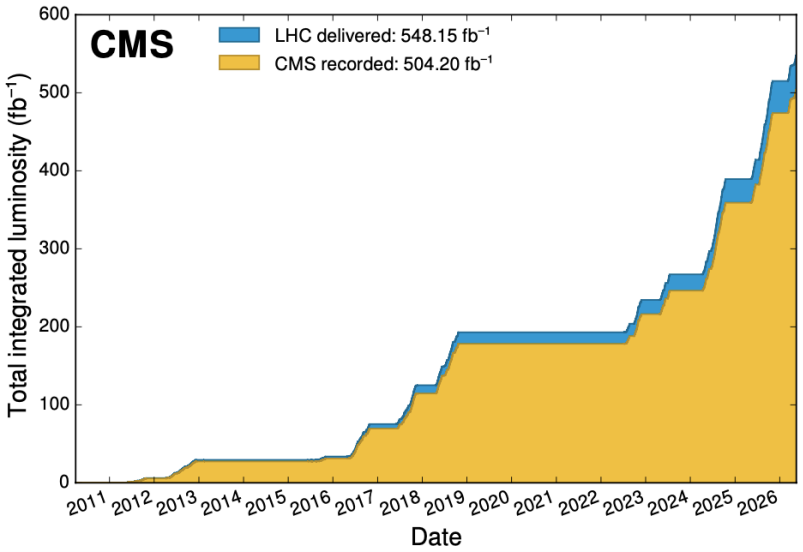
- The completion of LHC Run 3: data collected by CMS and the pathway towards the High-Luminosity LHC
- The broad CMS physics programme, from precision Standard Model measurements and QCD to Higgs and top-quark physics
- New opportunities in heavy-ion collisions and searches for physics beyond the Standard Model
- Expanding physics reach through advanced triggering, scouting and machine-learning techniques
- Preparing for the HL-LHC: the CMS Phase-2 detector upgrades and the next era of discovery

LHC Run 3 is completed

- Run 1 (2009 – 2012) at 7 and 8 TeV: 25 fb^{-1}
- Run 2 (2012 – 2015) at 13 TeV: 138 fb^{-1}
- Run 3 (2022 – 2026) at 13.6 TeV: 308 fb^{-1}

https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

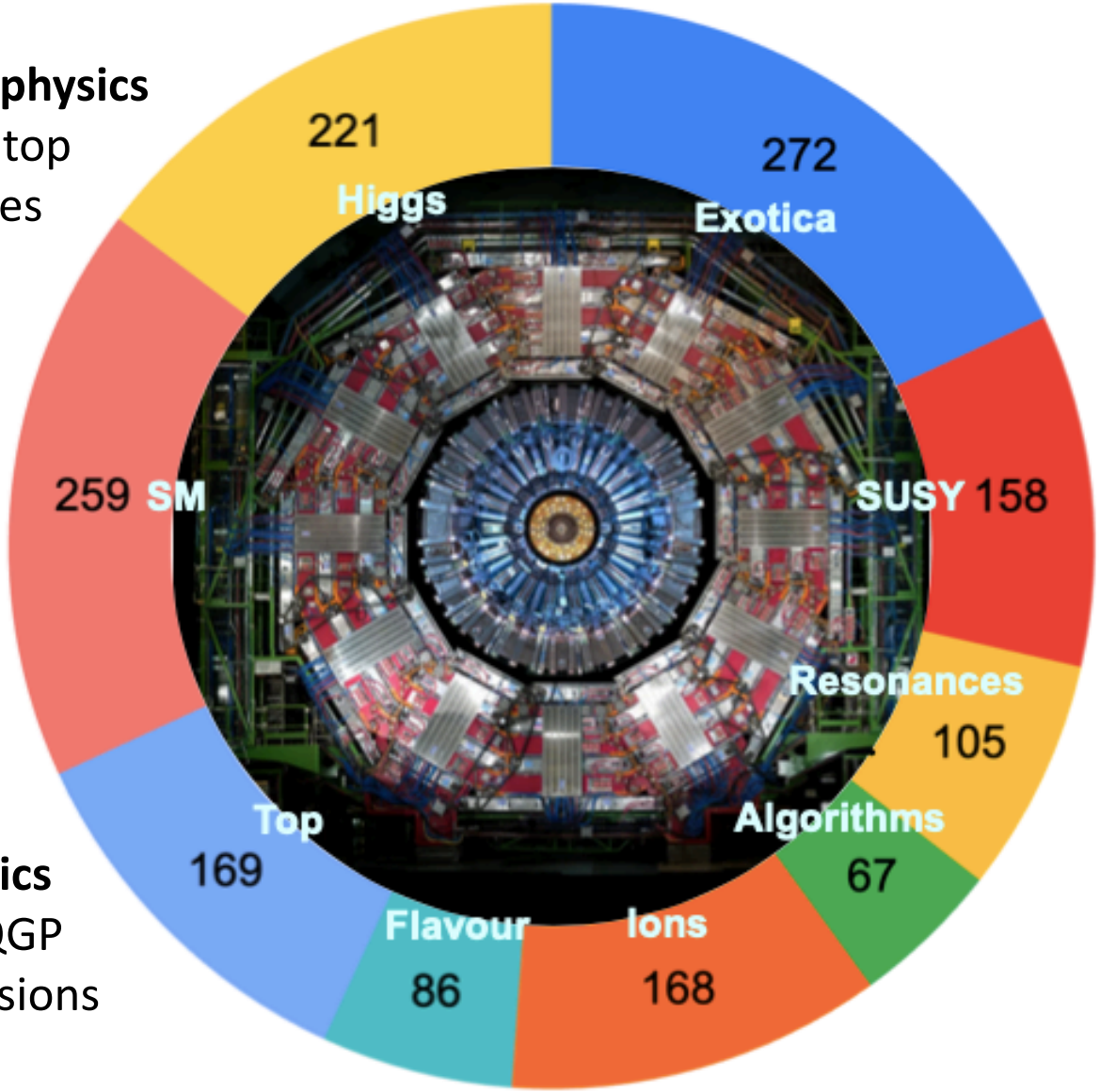




- around 0.5 ab^{-1} recorded over the total of 12 data taking years
- aiming for 3 ab^{-1} at HL-LHC with upgraded detector and trigger

Diverse and multi-frontier program of CMS physics

- **Standard Model & Higgs physics**
  - precision QCD, EWK, top
  - Higgs boson properties
- **Flavour physics studies**
  - spectroscopy
  - fragmentation
  - CP violation
  - rare decays
- **Heavy and light ion physics**
  - medium response, QGP
  - ultra-peripheral collisions

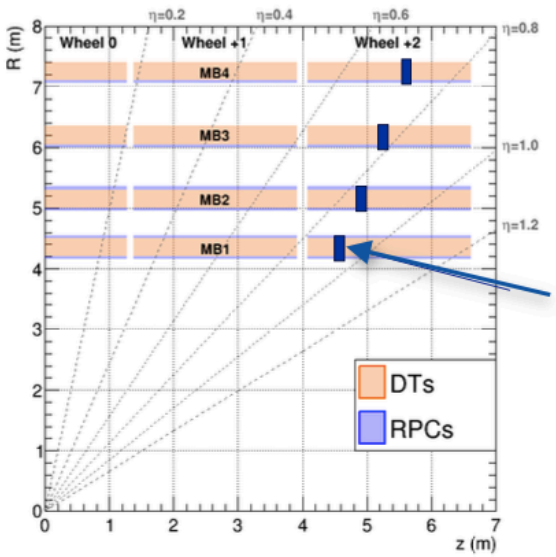


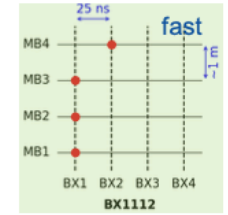
- **Searches for new physics**
  - high energy and high luminosity frontier
  - low mass and long lifetime of particles
  - anomalies detection
  - triggerless data taking
- **Improved detector, new technology & algorithms**
  - physics performance
  - ML, stat. techniques
- **> 1500 CMS publications:**

https://cms-results.web.cern.ch/cms-results/public-results/publications/

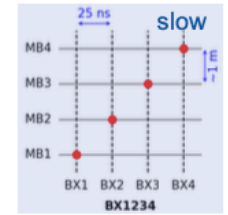
Improved triggering: Scouting at L1, Machine Learning at L1

- Scouting at L1 trigger: full L1 information is recorded

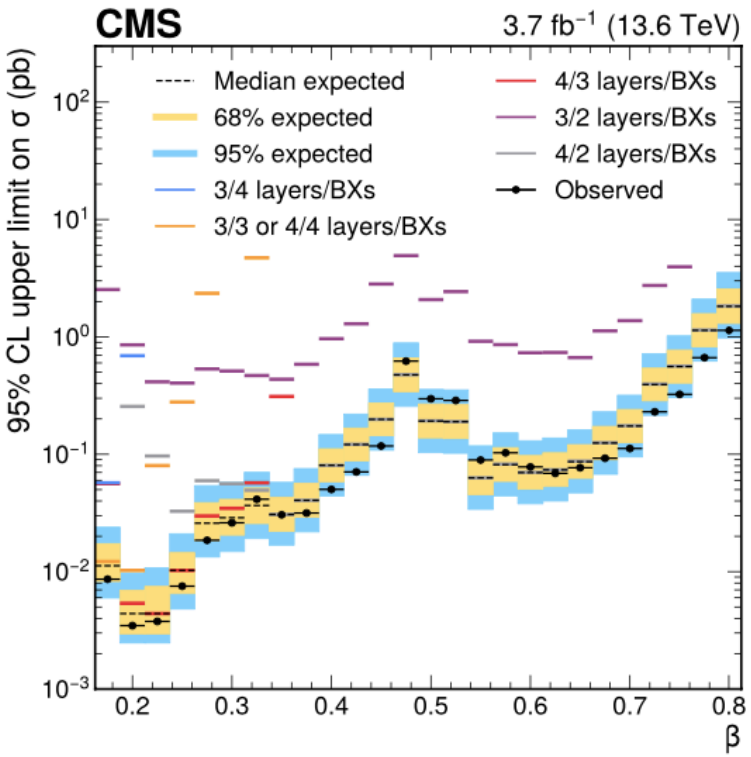




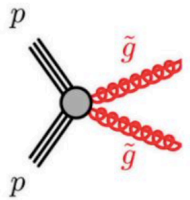
stubs in μ-system

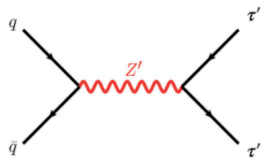


Phys. Lett. B 878 (2026) 140498

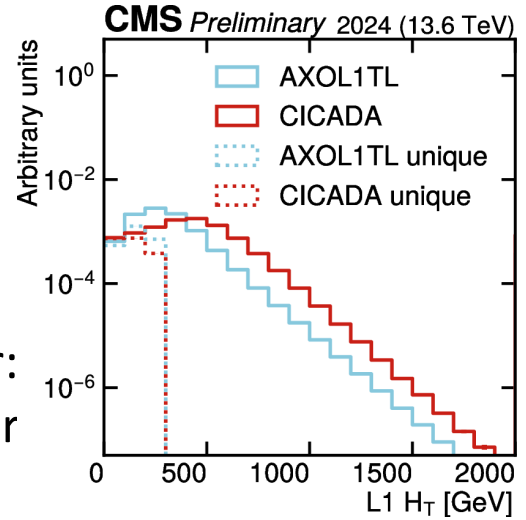


- First result: heavy stable charged particles search





CMS-PAS-MLG-25-001

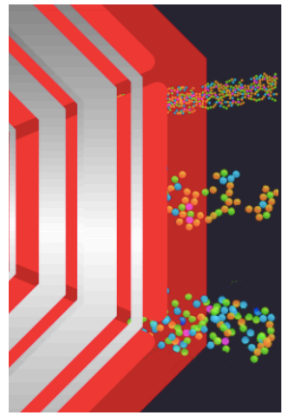


- Machine learning now also at L1 trigger: anomaly detection for μ and calo trigger

Improved triggering: HLT scouting, ML topological triggers

Physics Reports 1115 (2025) 678

- High Level Trigger (HLT): hybrid system CPU + GPU to reconstruct & select events
- HLT input/output rates reaching 110/40 kHz
- Scouting: only HLT objects (15kB/event), 600 B scouting events recorded in Run 3

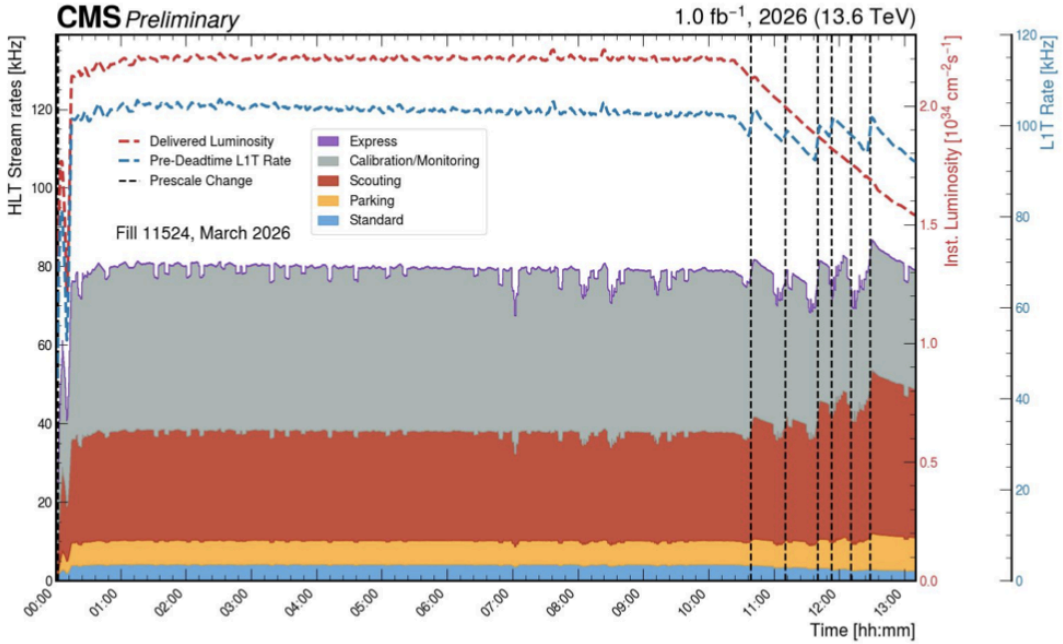


Scouting: ~30 kHz
15 kB/event

Parking: ~6 kHz
1 MB/event

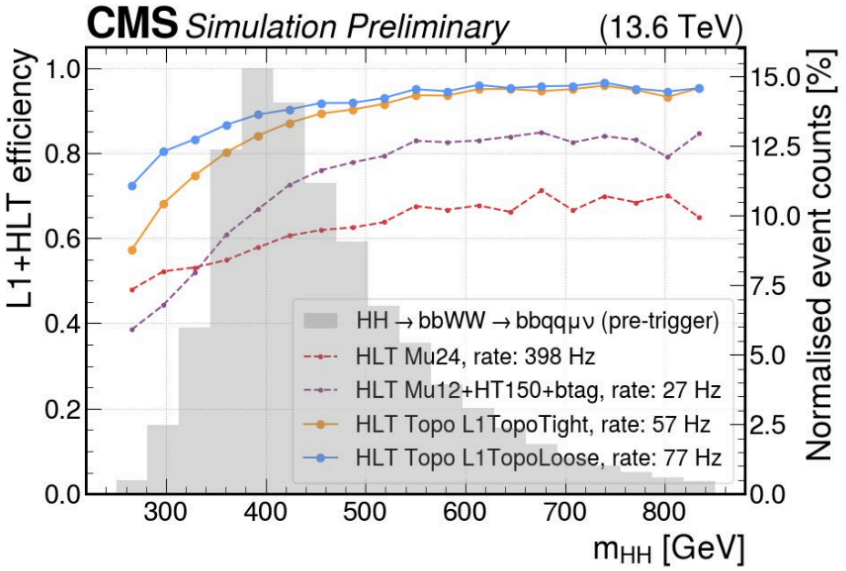
Standard: ~4 kHz
1 MB/event

CMS DP2026_023

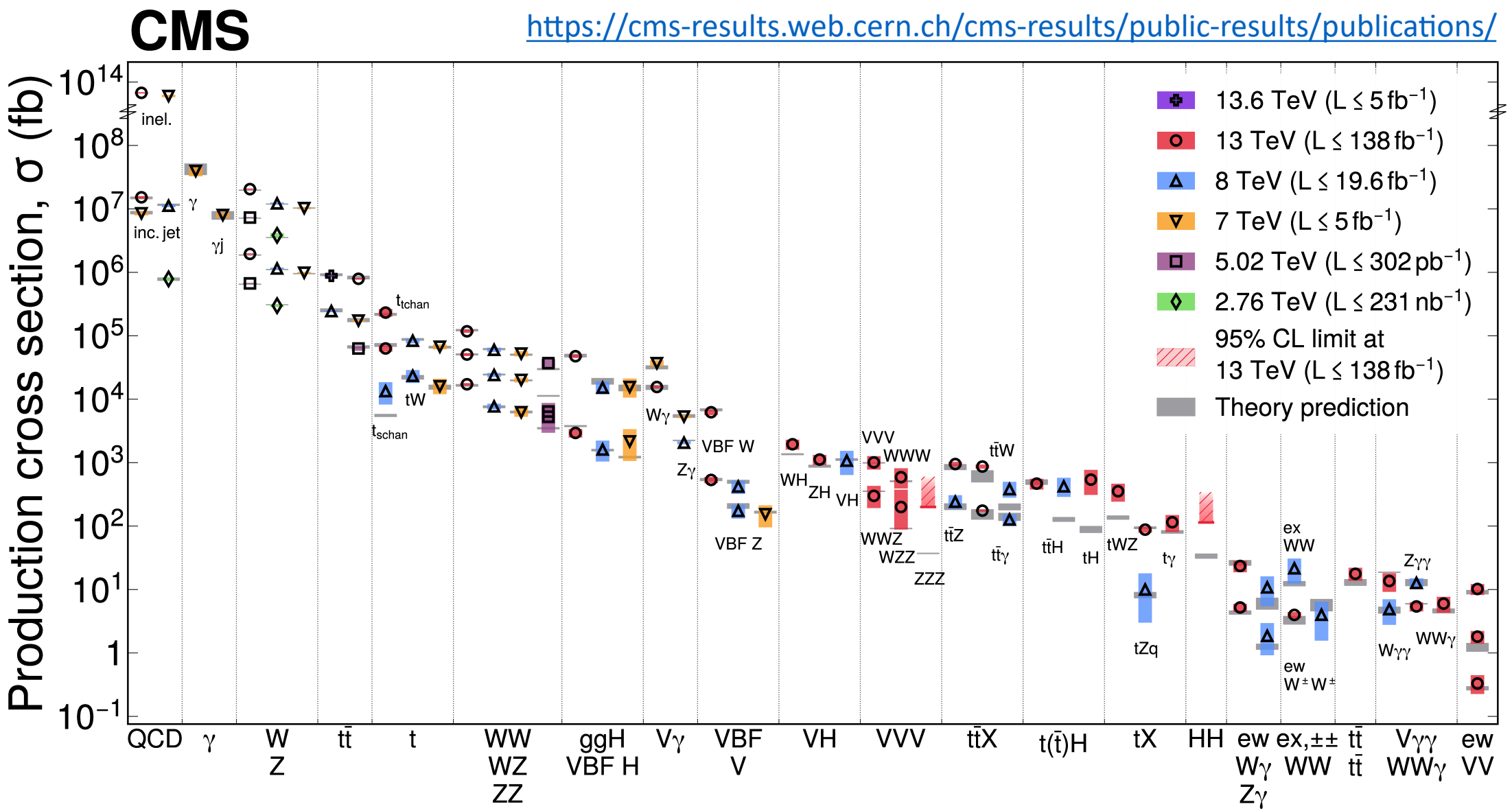


- Topological trigger: DNN at L1 and HLT deployed from 2026
- BDT based trigger to select HH events

CMS-DP-2026-027

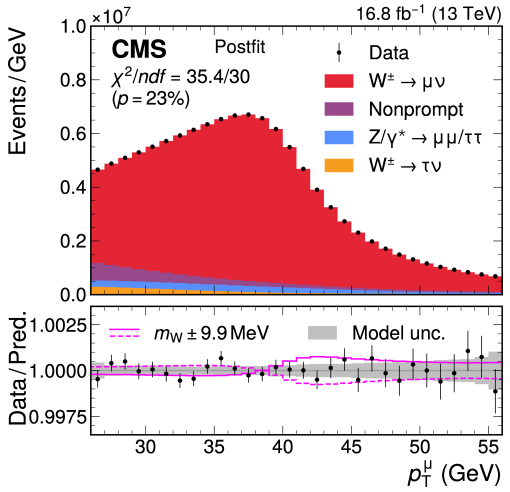


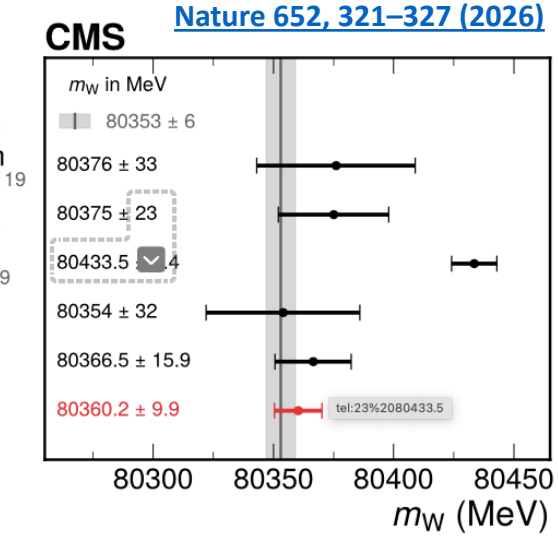
Stairway to Discovery



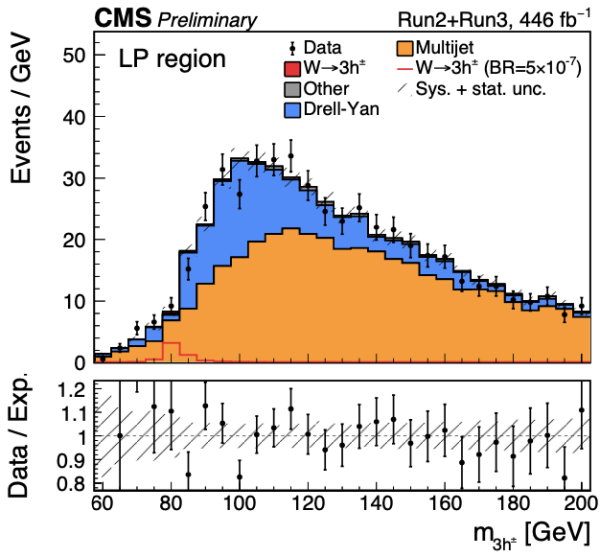
Standard Model: W boson measurements

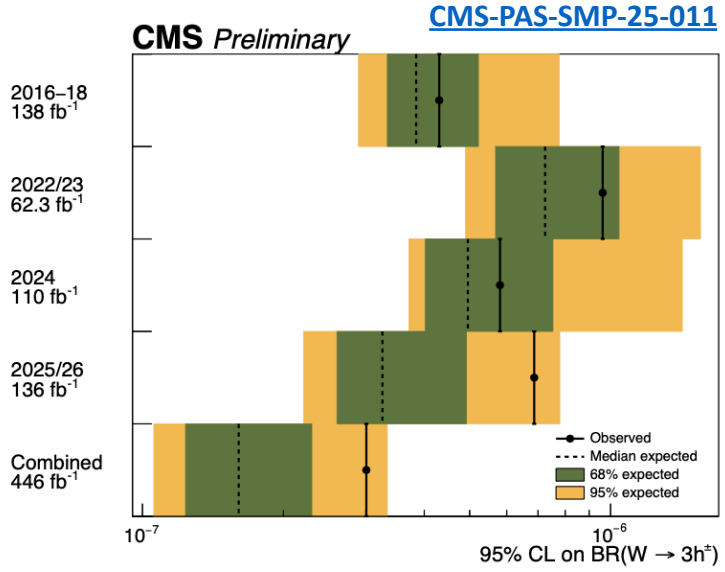
- High-precision measurement of the W boson mass
  - M_W = 80360.2 ± 9.9 MeV (from 2016 dataset)
  - new experimental techniques & state-of-the-art theoretical models, to improve accuracy
  - motivates low pileup and ultimate accuracy





Nature 652, 321–327 (2026)



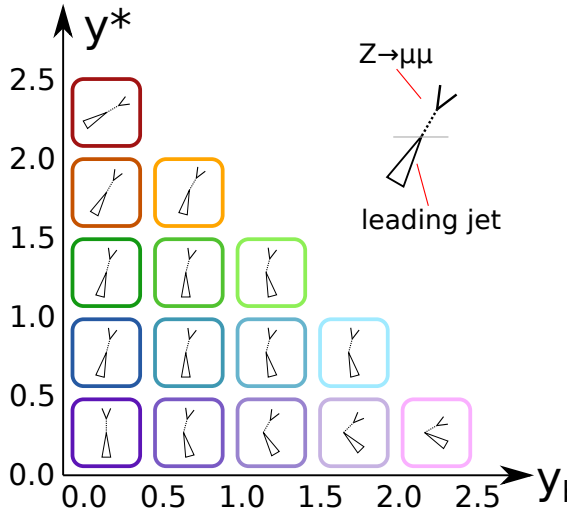


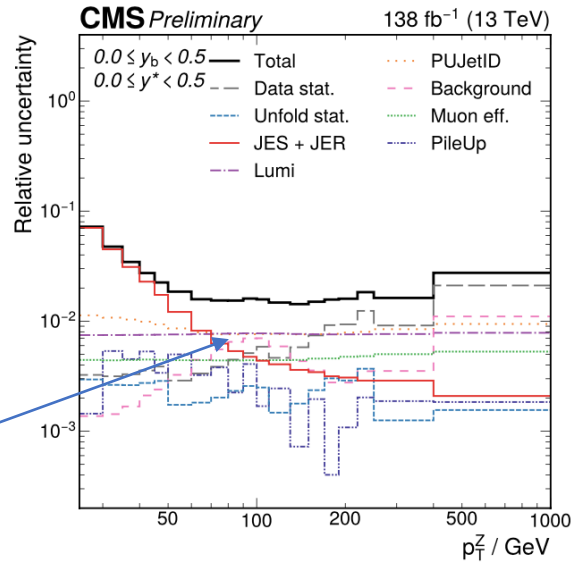
CMS-PAS-SMP-25-011

- Search for W boson decays to three charged hadrons
  - B(W→3h) < 2.4 × 10−7 (95% CL)
  - Run 2 + Run 3 data set: 446 fb−1
  - B(W± → 3π±) ~ O(10^{-7}–10^{-5})
  - Accurate predictions for the exclusive decay would access precise QCD probe (at HL-LHC)

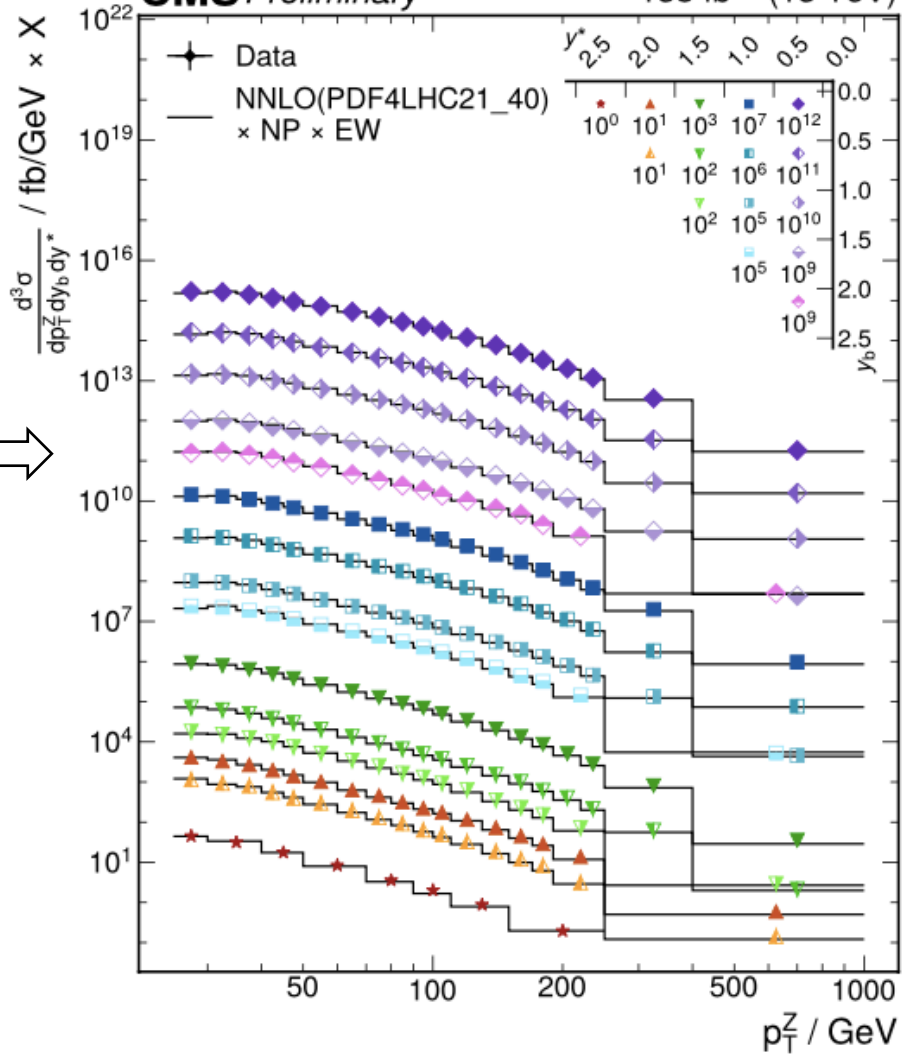
Standard Model: Triple Differential Z+Jets cross section

- Unfolding performed in $p_t(Z)$, y_b and y*
- Constrains parton density distributions
- Unfolded cross section of $Z/\gamma*(\rightarrow \mu\mu)$ + jet production for each (y^b, $y*$) bin as a function of p_T^Z with NNLO PDF4LHC21
- Bulk uncertainty was measured at 1.5%
- Run 2 int. luminosity uncertainty: 0.73%





CMS PAS SMP-24-010

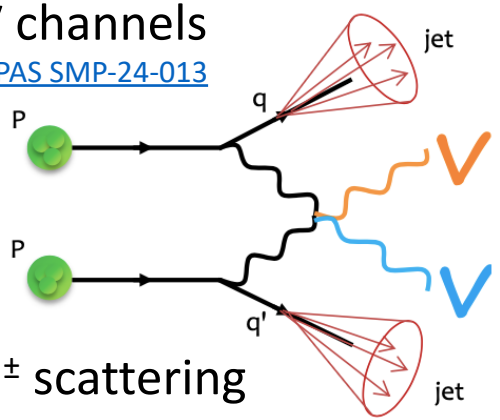


Standard Model: Vector boson & lepton-lepton scattering

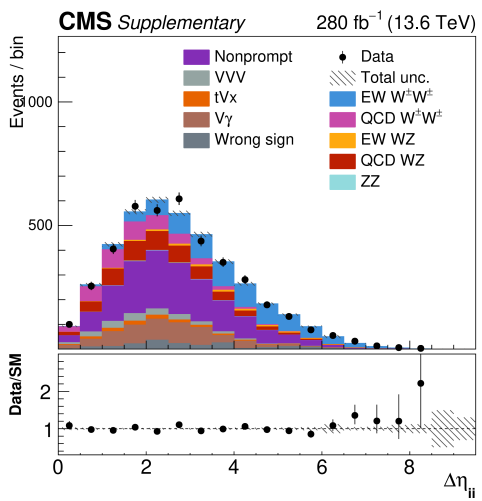
- Run 2: evidence for VBS in all massive-V channels
  - same was found in γ - γ collisions
- Run 3: first differential VBS x-sections

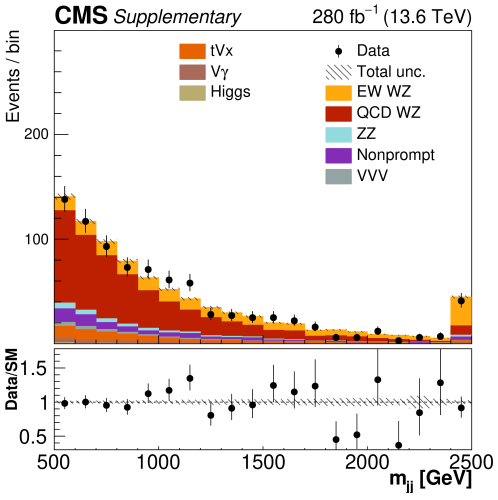
CMS PAS SMP-24-013

JHEP 06 (2026) 187



CMS-SMP-25-013

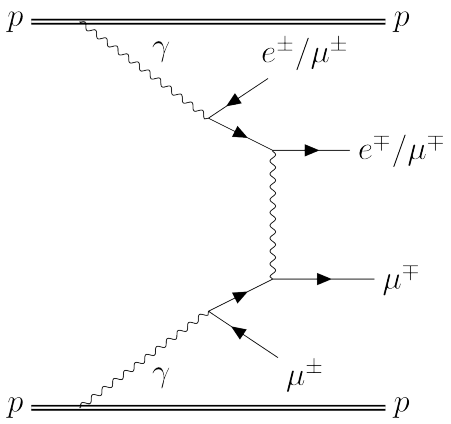


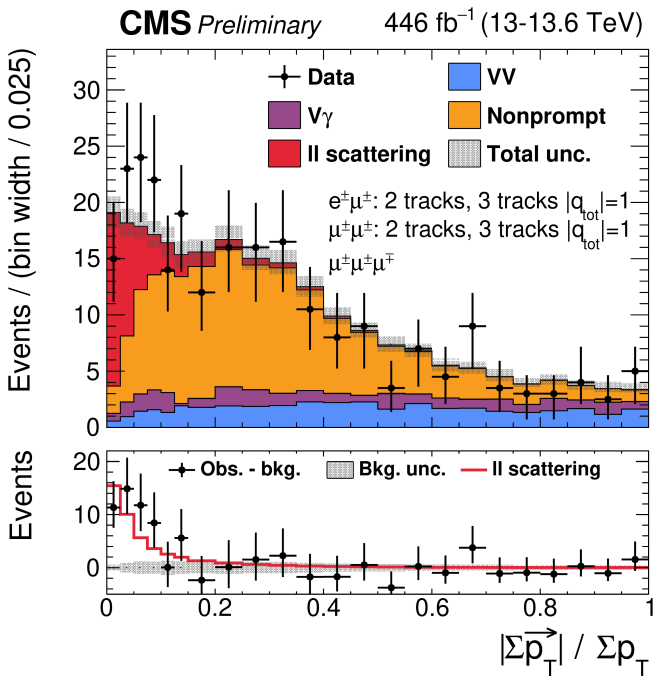


- New probe of QED partonic structure: $l^{\pm}l^{\pm}$ scattering

CMS-SMP-26-008

- Same-sign $e^{\pm}\mu^{\pm}$ and $\mu^{\pm}\mu^{\pm}$ pairs scatter in a photon exchange



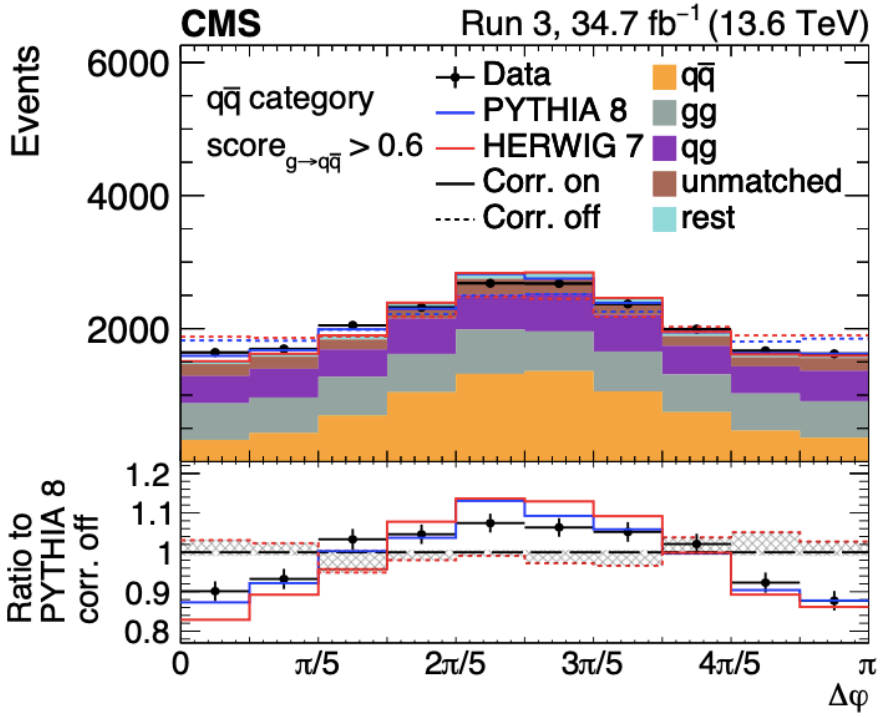


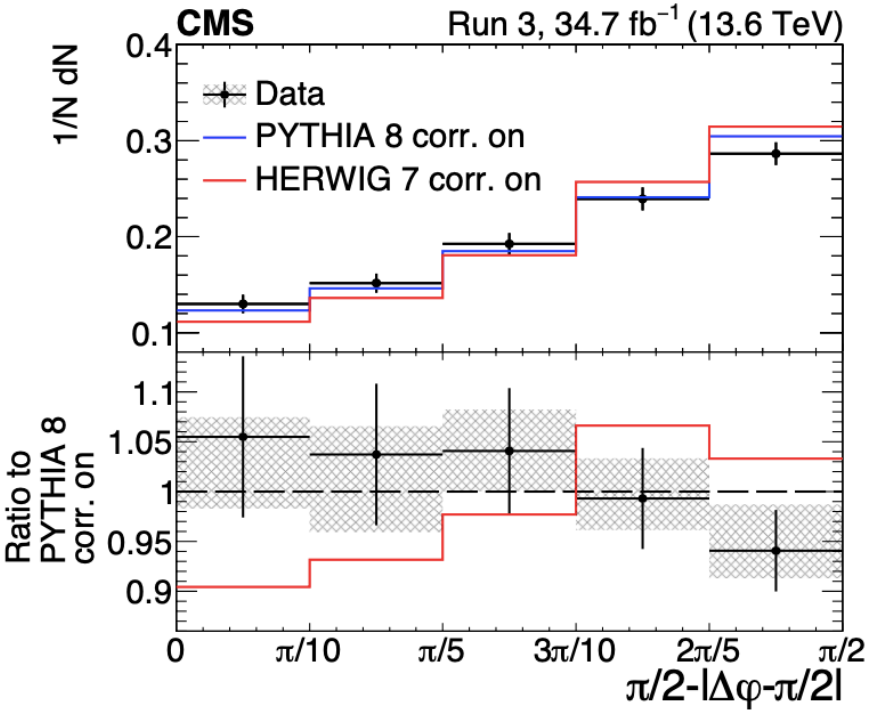
- Signal: elastic+single-dissociative: quiet multilepton vertex
  - ≤ 4 tracks and small p_t balance, simulated w/ SFGen
  - four event categories: $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$ and $\mu^{\pm}\mu^{\pm}\mu^{\mp}$
  - total of 446 fb^{-1} recorded at $\sqrt{s}$ = 13 and 13.6 TeV
  - systematics: nonprompt/pileup, survival probability at low number of tracks (Eur.Phys.J.C 80 (2020) 10)
- This is the first observation of scattering between leptons radiated from the incoming protons; 5.4 σ ($\mu^{\pm}\mu^{\pm}$ at 4.0 σ)

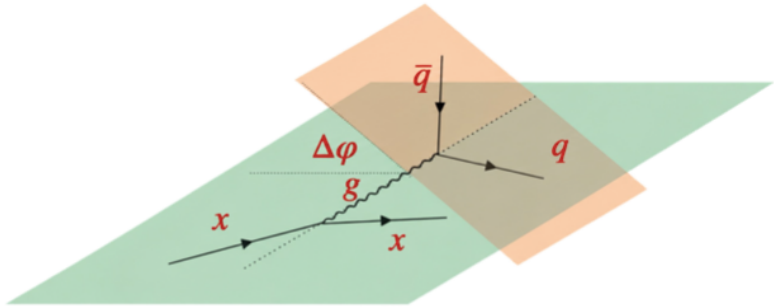
Standard Model: Gluon spin correlation inside jets

CMS-PAS-SMP-25-006

- Gluon polarization induces spin correlations *within* jets
  - Run 3 (2022): 34.7 fb^{-1} at $\sqrt{s}$ = 13.6 TeV
  - CA declustering of p_t > 700 GeV AK8 jets
  - Observable: Δϕ between successive splitting planes







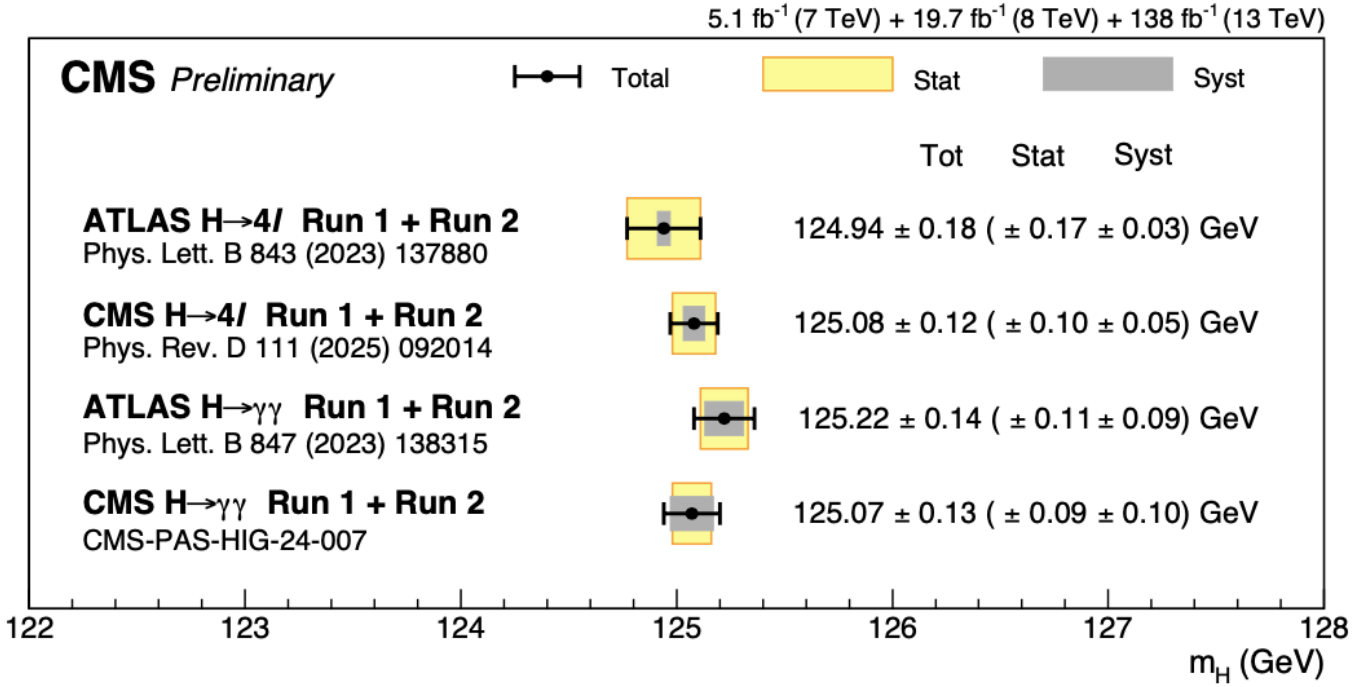
- ML isolates g→qq̄ splittings, where modulation is largest
- "No correlations" is disfavored by 6.8σ; Pythia within unc.
- Herwig (= spin density matrix) predicts a stronger effect

One step towards precision of boosted hadronic Higgs decays

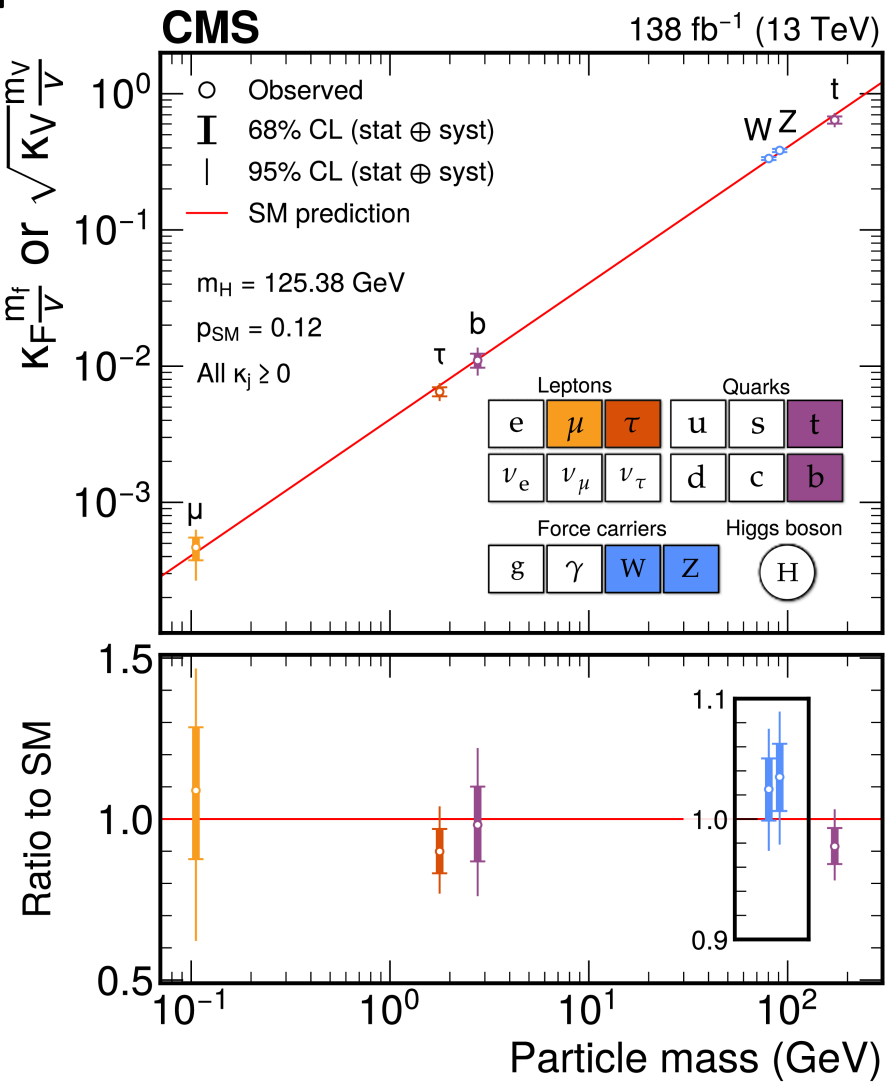
Higgs physics: Precision measurements and couplings

- Higgs in γγ: Comprehensive Run 1+2 mass combination [HIG-24-007]
  - $M_{H(\gamma\gamma)}$ = 125.07 ± 0.09 (stat) ± 0.11 (syst) GeV
- Cross sections (STXS), couplings, 2HDM constraints [HIG-21-018]
  - 32 kinematic regions encompassing ggH, VBF, WH and ZH
  - **$\mu = 1.014\ ^{+0.055}_{-0.053}$** - follow mass-proportional SM pattern
- 2nd generation lepton-couplings [HIG-19-006]

CMS-PAS-HIG-24-007



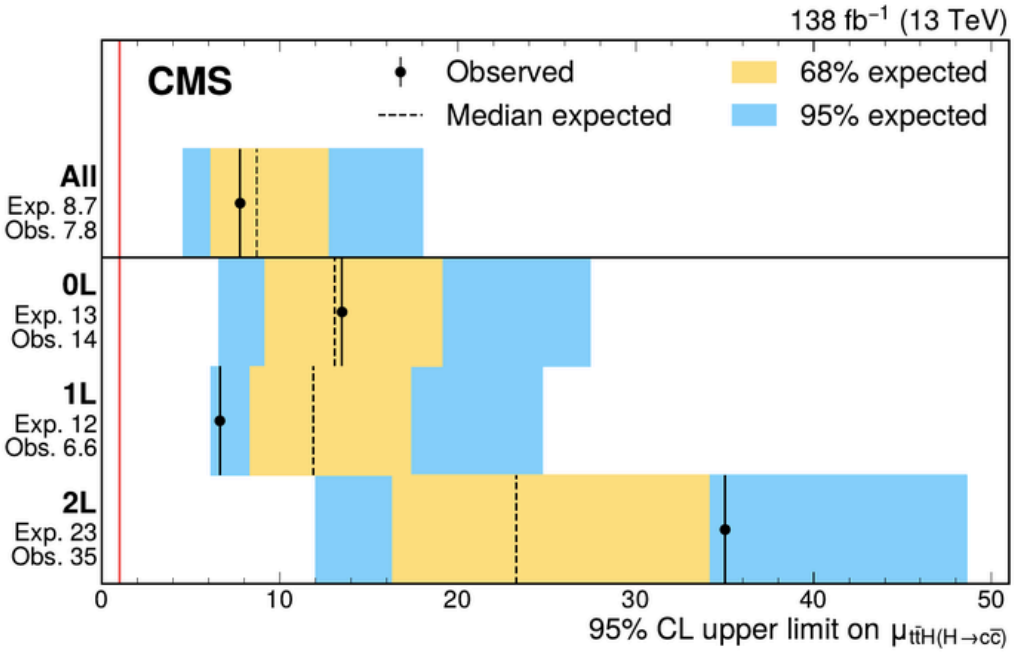
Rep. Prog. Phys. 89 (2026) 087801

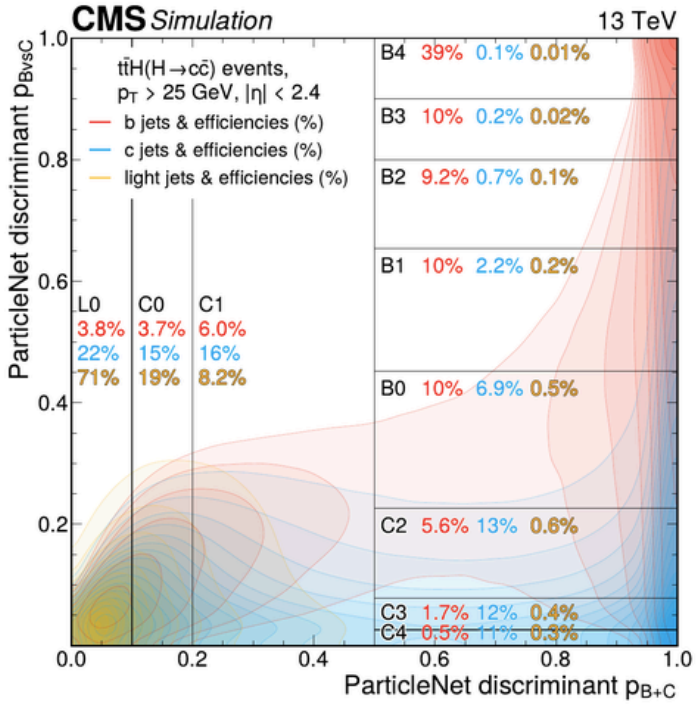


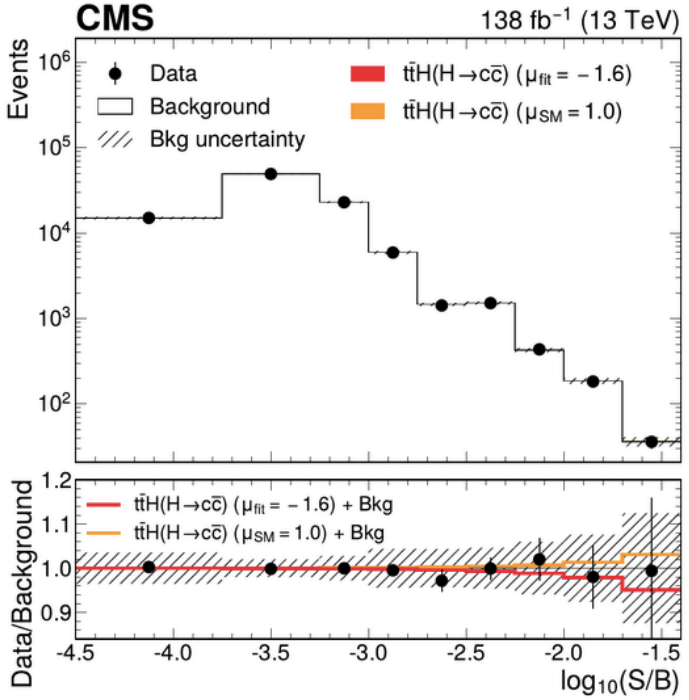
Higgs physics: coupling to charm quark

- 2nd fermion generation: H→cc; considered infeasible at the LHC – requires c tagging and QCD backgrounds
- ParticleNet (dGCNN) separates b, c, and light jets, for enabling a dedicated ttH (where H→cc) Run 2 search
- 138 fb^{-1} at 13 TeV: μ(ttH(cc)) < 7.8 (8.7 exp) at 95% CL

CMS-HIG-24-018





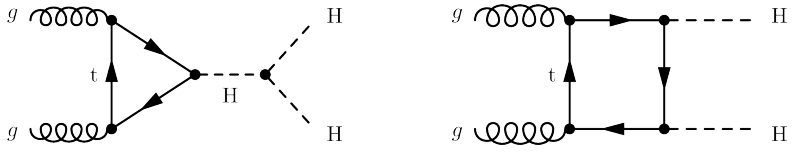


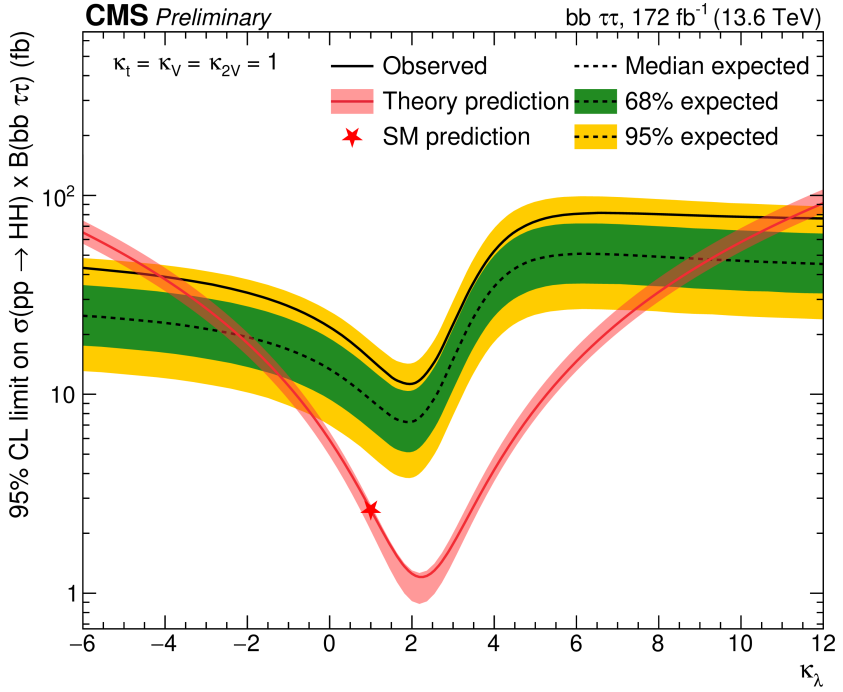
- Combination with VH (H → cc) channel:

  |κc|< 3.5 (2.7) obs. (exp.) [HIG-21-008]

Higgs physics: HH production – from Run 2 to Run 3

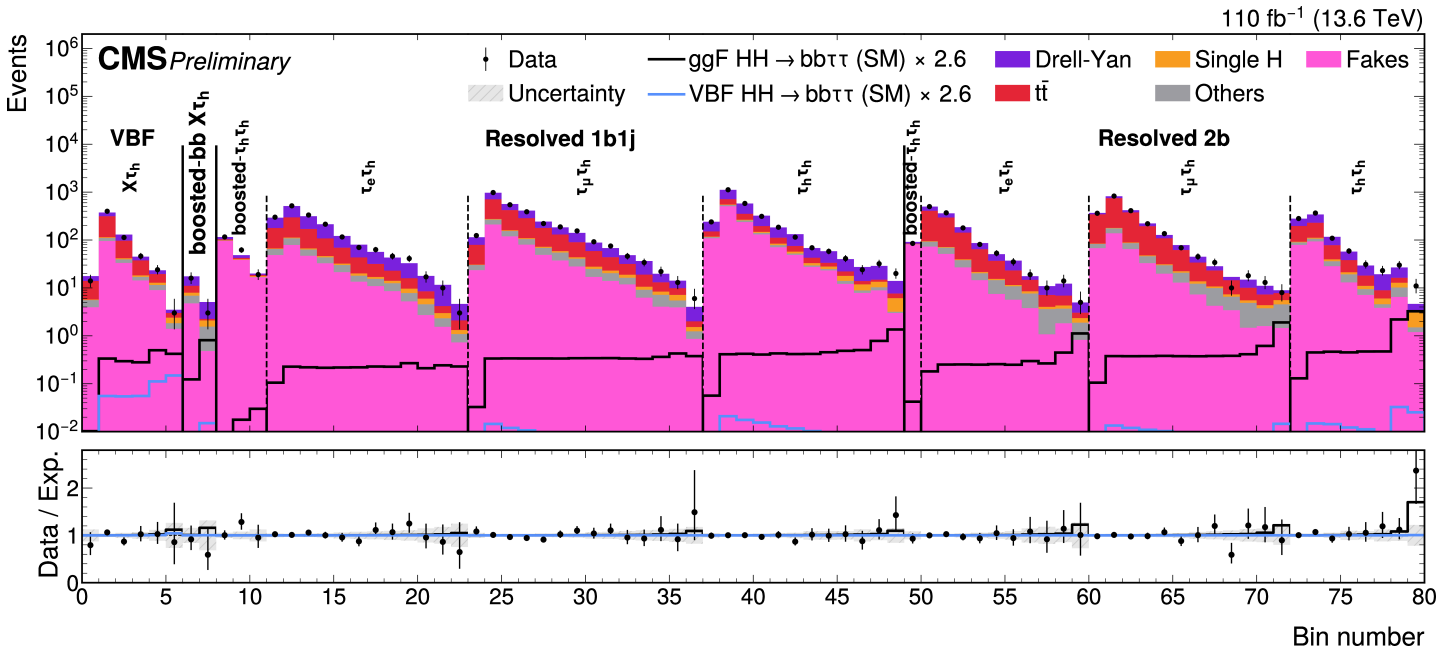
- κ_λ is the SM test because the Higgs potential is largely unconstrained



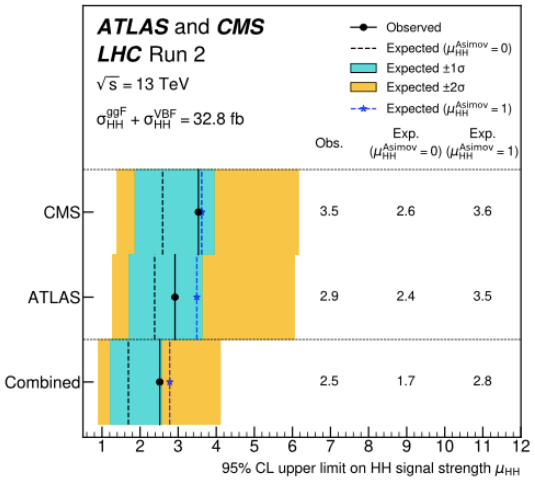


ATLAS + CMS $\mu_{HH} = 0.8^{+0.9}_{-0.7}$ [HIG-25-014]

CMS-PAS-HIG-25-008

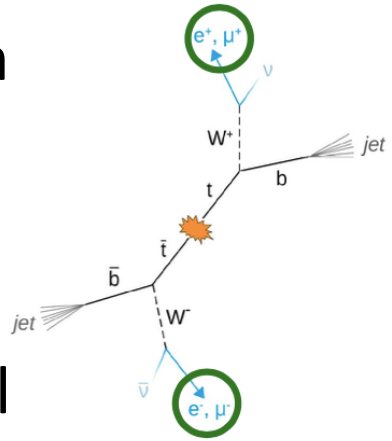


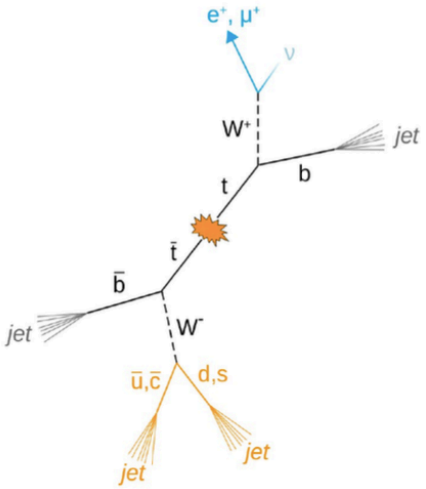
- Interference with top Yukawa coupling
- ATLAS+CMS Run 2 yielded $\mu_{HH} = 0.8^{+0.9}_{-0.7}$
- CMS results made with partial Run 3 data
- μ(HH→bbττ) < 4.0 (3.0 exp)xSM at 95% CL
- Run 2 + Run 3 combination with 0.3 ab-1



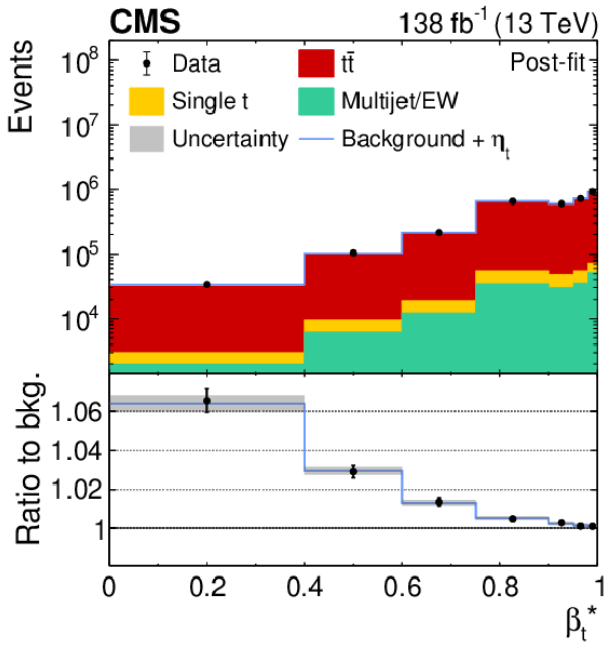
Top physics: excess in ttbar production at threshold

- Excess is consistent with pseudoscalar toponium
- 2024: first observed by CMS in dilepton channel

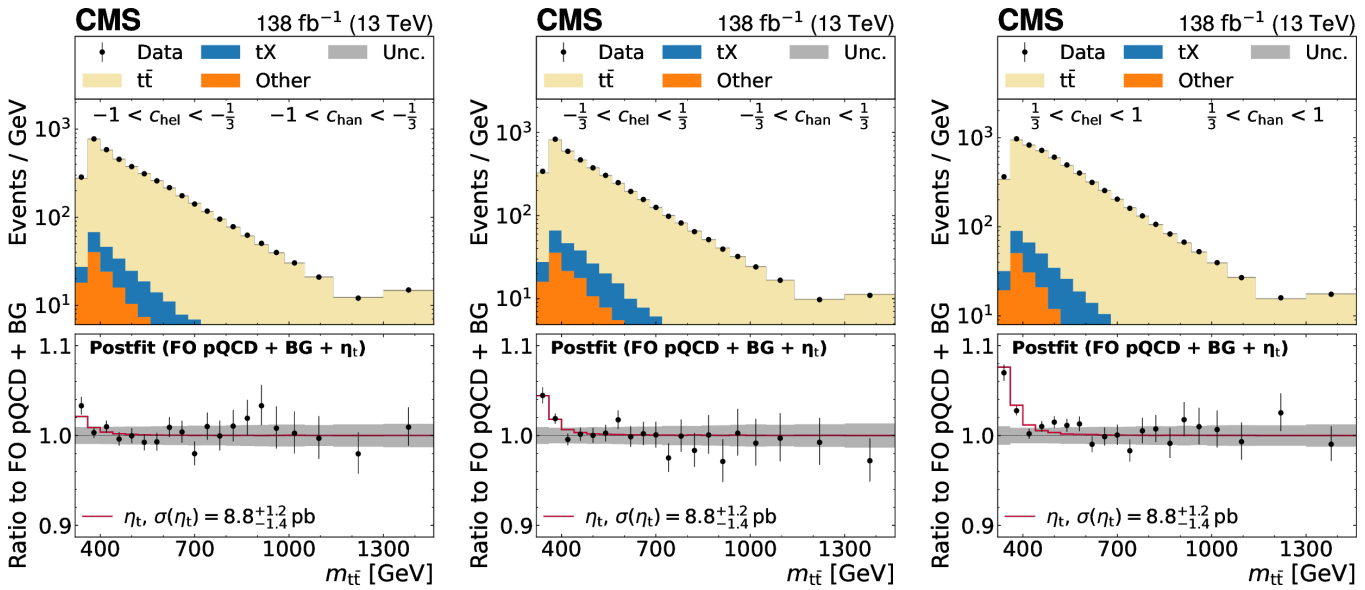




Submitted to Reports on Progress in Physics



Rep. Prog. Phys, 88 (2025) 087801



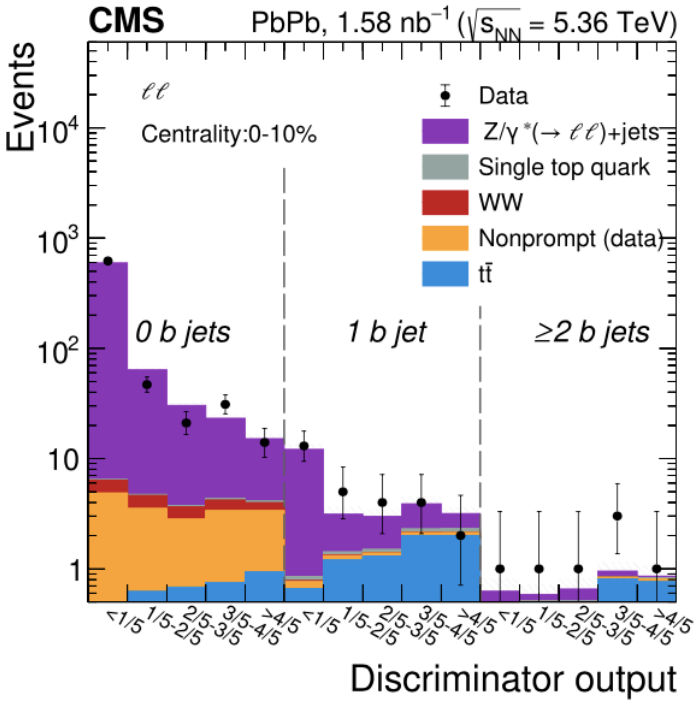
- Fit in m_{tt} in bins of c_{hel} & c_{han} (c_{hel}: cos(l,t) in t rest frame)
- 2026: independent analysis in the l + jets channel
- Fit in β_t^*,c_{hel}, c_{han}, S_{NN} and b tag; β_t^* is velocity of t_l in t_h rest frame; S_{NN}: ttbar reco significance

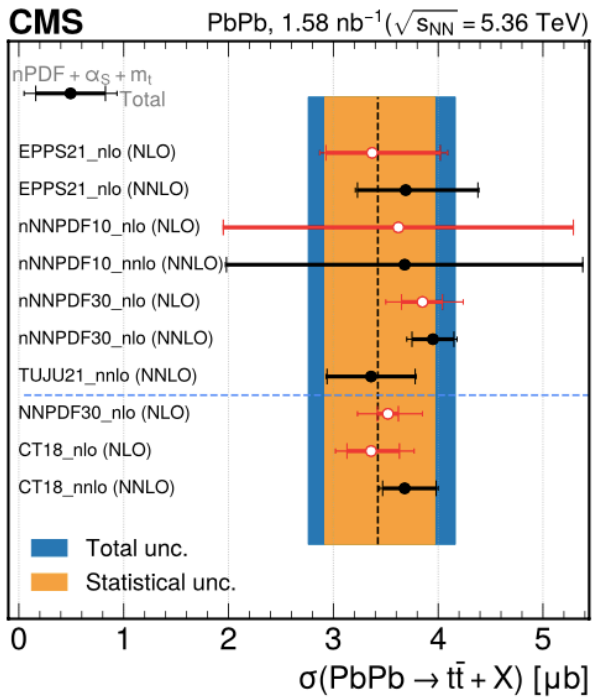
$8.8^{+1.2}_{-1.4}$ pb (dileptons) and 5.3 ± 0.9 pb (single lepton)

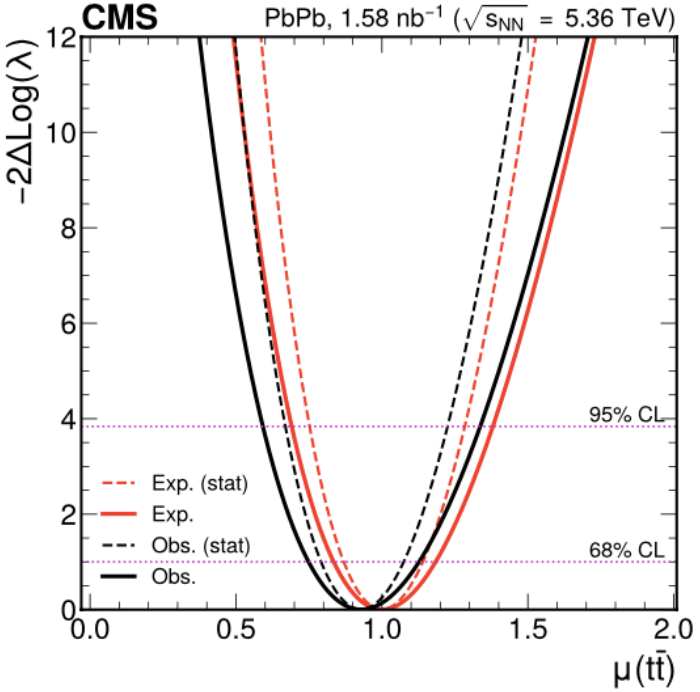
Top/HIN physics: top quark pairs in PbPb

JHEP 08 (2026) 054

- First measurement of top quark pair production in PbPb collisions
- PbPb dataset: 1.6 nb^{-1} at center-of-mass energy of 5.36 TeV (2023)
- Selection applied on dilepton events and b-jet multiplicity separate top quark pair signal events from Drell–Yan and other backgrounds







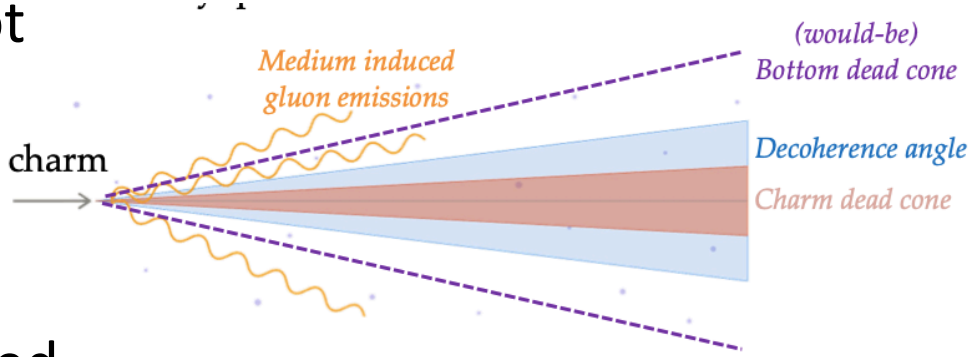
- New techniques:
  - electron ID (BDT)
  - lepton isolation (from SoftKiller)
  - JES calibration
  - Heavy flavor jet ID (UPart)

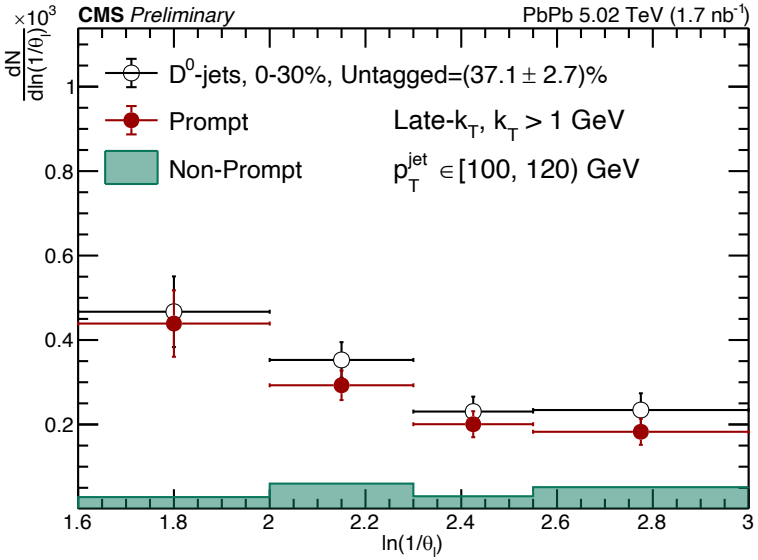
$\sigma(t\bar{t}) = 3.42^{+0.54}_{-0.51}\ (stat)\ ^{+0.50}_{-0.43}\ (syst)\ \mu b$
- consistent with nuclear-PDF calculations

tt/Z is sensitive to gluon and quark nPDF ratio
- discriminates nPDF sets with more data

HIN physics: dead cone of charm quarks in PbPb

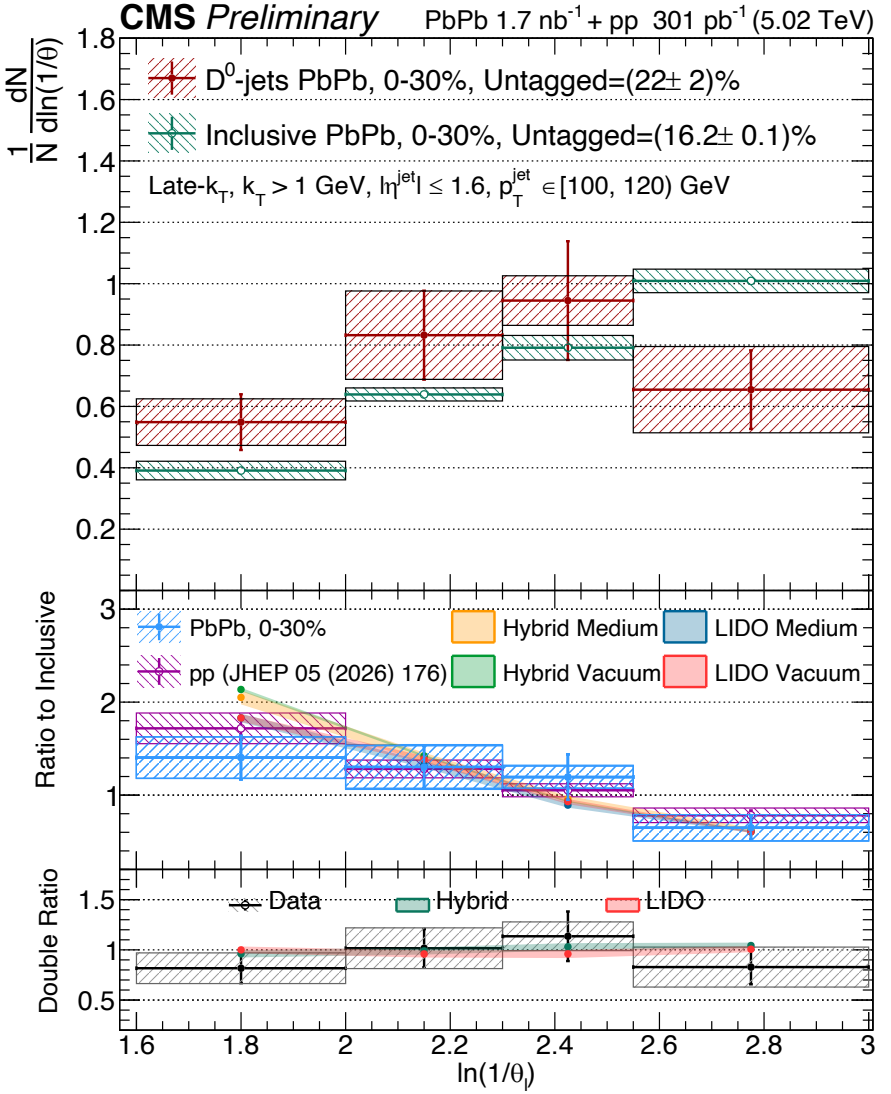
- QGP medium can not resolve angular structure below a decoherence angle
- Does medium-induced radiation fill the dead cone of a heavy quark?





- PbPb data: 1.7 nb^{-1} at $\sqrt{s_{nn}}$ = 5.02 TeV (2018)
- Prompt D-tagged jets isolate charm-quark radiation; late-k_t selects hard, collinear splittings
- The small-angle suppression persists: the PbPb/pp double ratio is consistent with unity

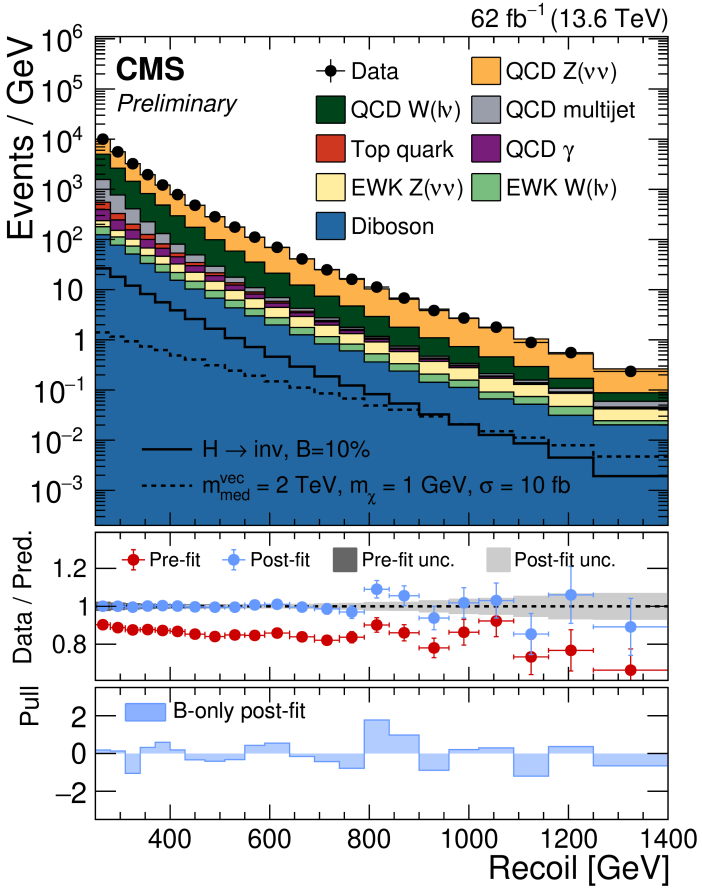
CMS-PAS-HIN-25-013



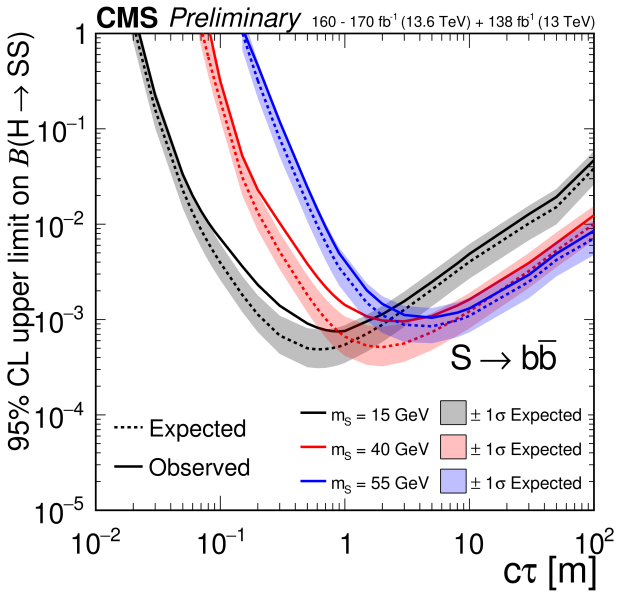
Searches for invisible or long-lived particles

CMS-PAS-NPS-25-008

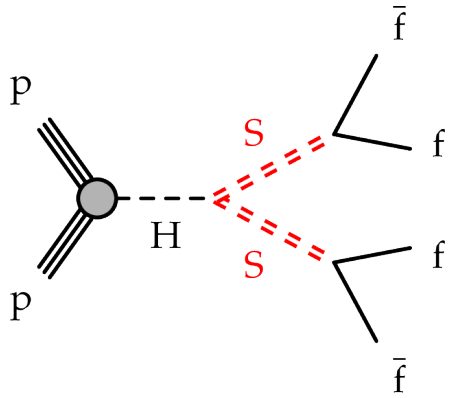
- New physics in events with >=1 energetic jets and large missing p_T
  - generic p_T miss precision search: DM, H->inv, extra-dimensions
  - Z -> νν background from fit to Z -> ll, W -> lν and γ+jets events
- For m_{DM} ~ 1 GeV, m_{med} < 1.9 TeV, B(H->inv) < 42% (39% exp) at 95% CL



CMS-PAS-EXO-25-005



- Long-lived particles producing showers in the muon system
- High multiplicity muon trigger added in Run 3



- Limits on B(S->dd, bb, ττ) for the values of cτ between 1 cm and 100 m

CMS upgrades for HL-LHC

New inner tracker

- all silicon made
- 4 pixels, 5 strips
- $|\eta| < 4$

CMS-TDR-014

New precision timing detector

- timing resolution of 30-40 ps for MIPs
- $|\eta| < 3.0$ coverage

CMS-TDR-020

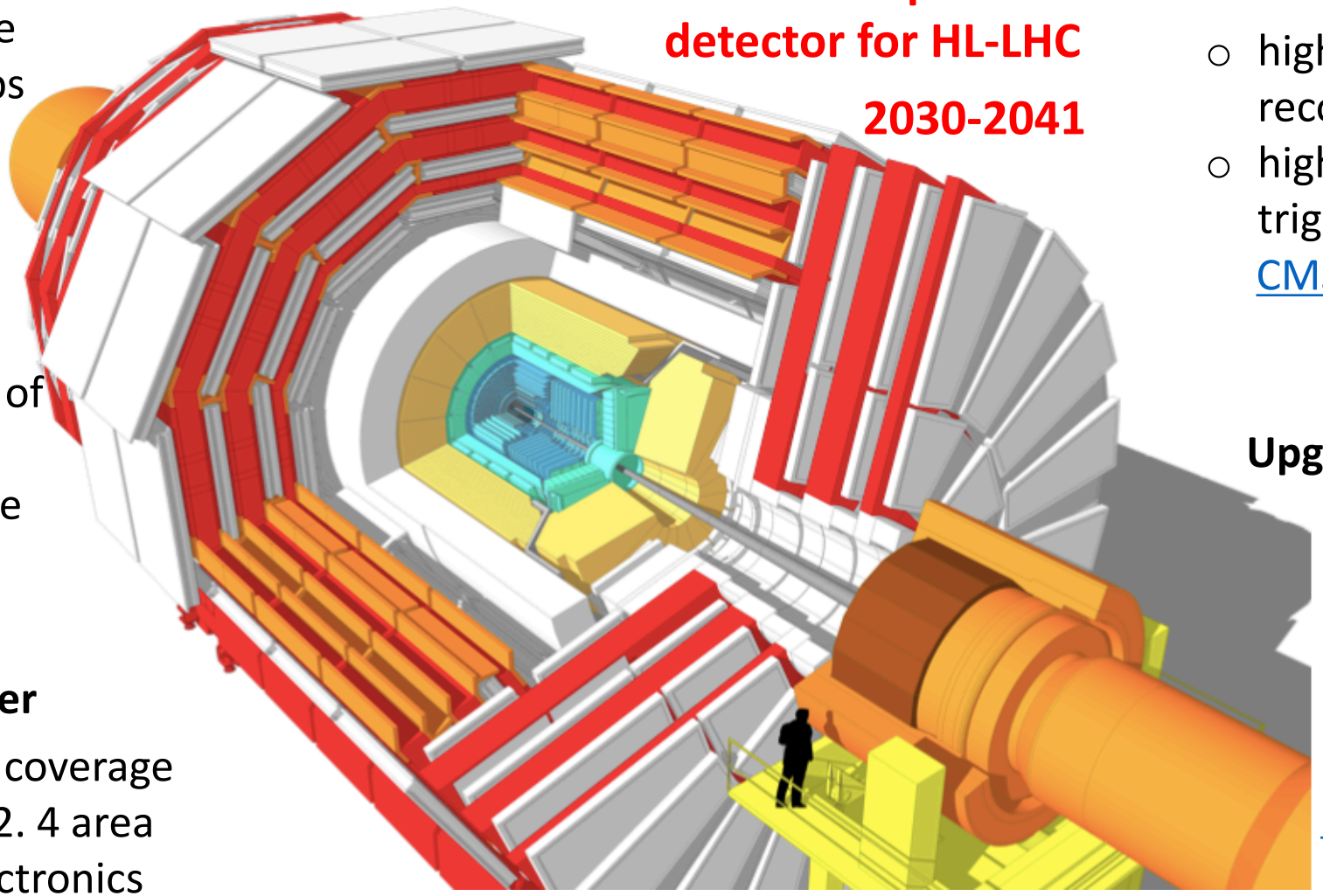
Improved muon coverage and trigger

- Increased RPC coverage to $1.5 < |\eta| < 2.4$ area
- new muon electronics

CMS-TDR-016

Have the best possible detector for HL-LHC

2030-2041



Optimal coverage and resolution already at trigger level

New endcap calorimeters

- high granularity, shower reconstruction now in 3D
- higher granularity also for trigger system electronics

CMS-TDR-019

Upgrade trigger and DAQ

- L1 rate to 750 kHz
- HLT rate to 7.5 kHz
- track information added to L1 trigger

L1: CMS-TDR-021

DAQ/HLT: CMS-TDR-022

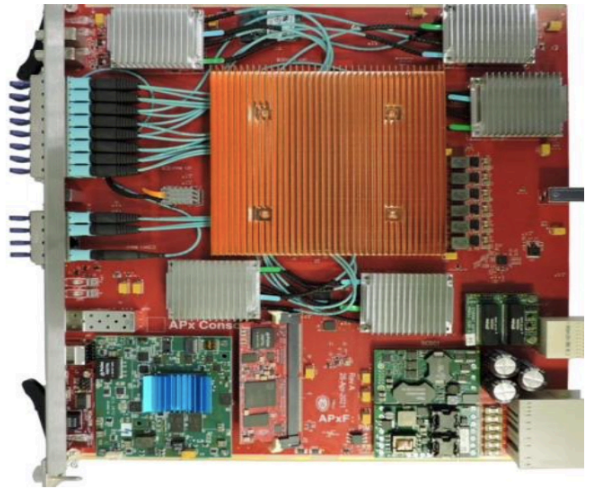
Progress of CMS Phase-2 construction



integration of tracker barrel



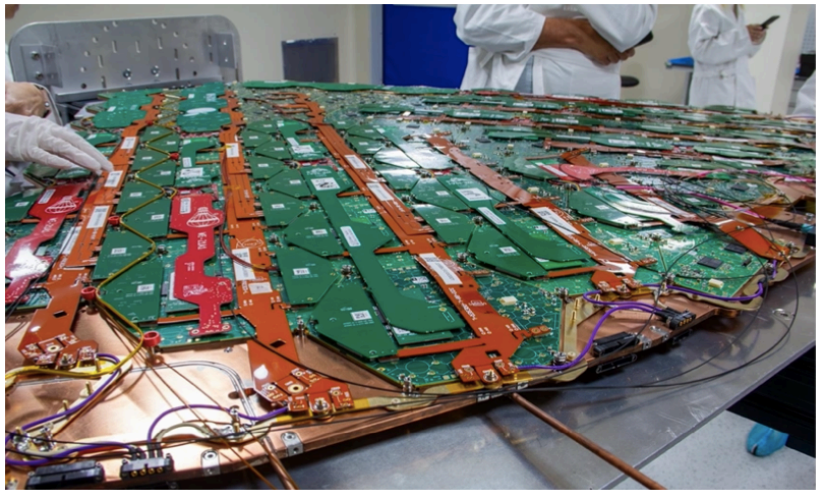
Assembly of MTD trays and tracker-ladder



Prototype of L1 trigger-board



Insertion of ECAL supermodule



Assembly of HGCAL cassette



Precision module assembly

Summary and Outlook

- Run 3 is complete, with 308 fb^{-1} recorded at 13.6 TeV and about 0.5 ab^{-1} collected across Runs 1–3.
- Precision Standard Model measurements and new QCD and electroweak probes continue to push the boundaries of our knowledge and understanding.
- The Higgs and top programmes explore increasingly subtle properties, from charm couplings and Higgs-pair production to the top-pair threshold studies.
- Heavy-ion results provide new insight into QGP dynamics, while searches for invisible and long-lived particles continue to test exciting new-physics scenarios.
- Advanced scouting and ML-based triggers are expanding CMS capabilities, while Phase-2 upgrades prepare the detector for the HL-LHC and its target of 3 ab^{-1}.

THANK YOU FOR THE ATTENTION!

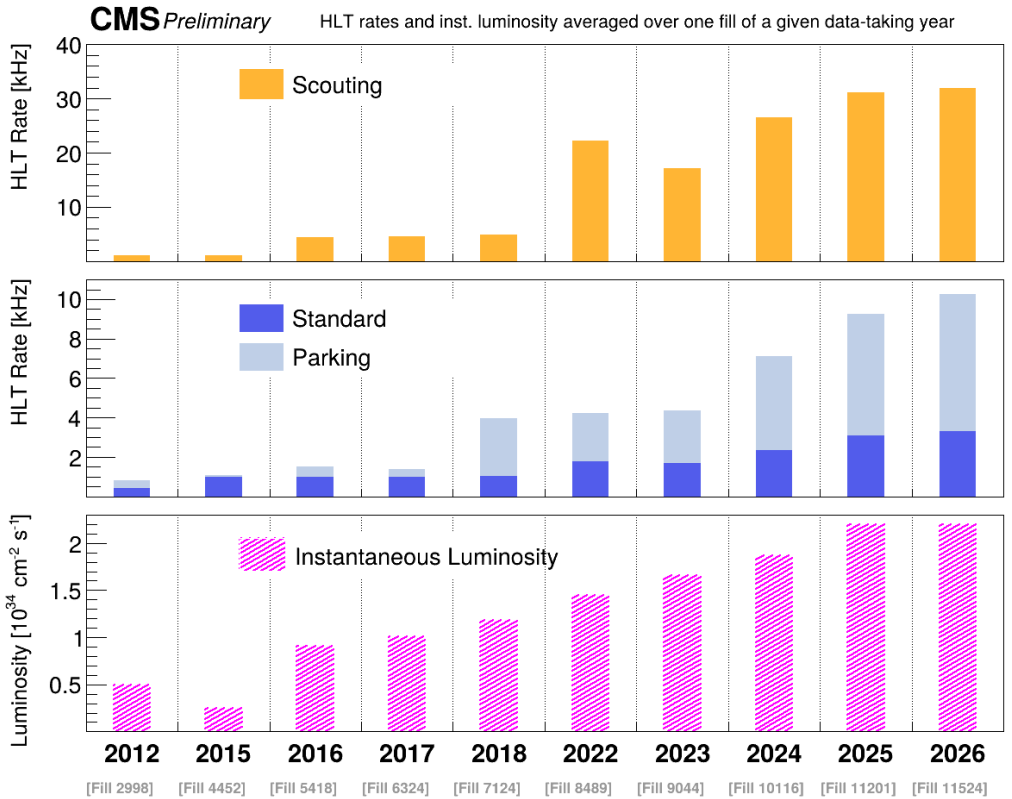


BACKUP SLIDES

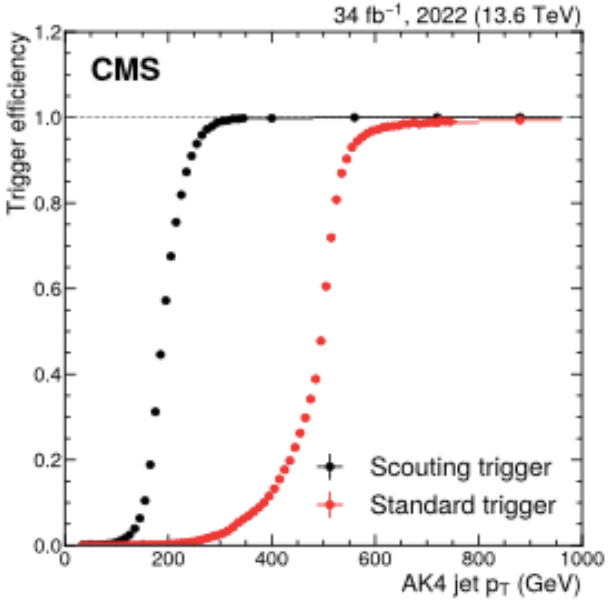
Improved triggering: HLT+L1 scouting, ML at trigger level

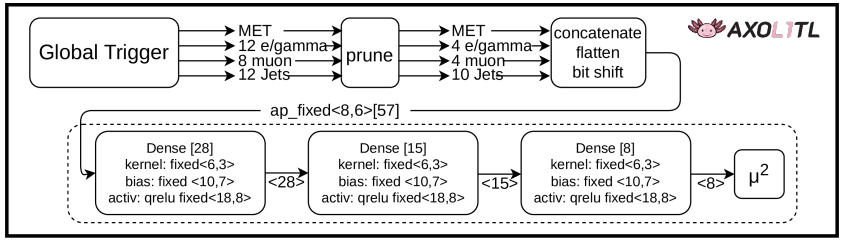
CMS-PAS-MLG-25-001

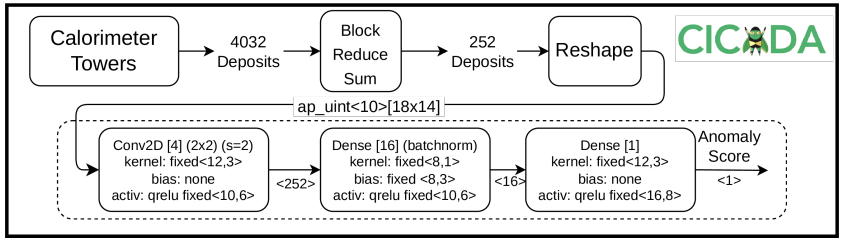
CMS DP2026_023



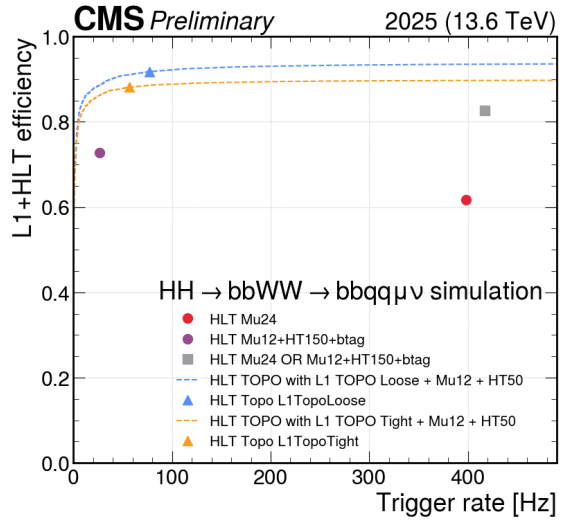
Physics Reports 1115 (2025) 678





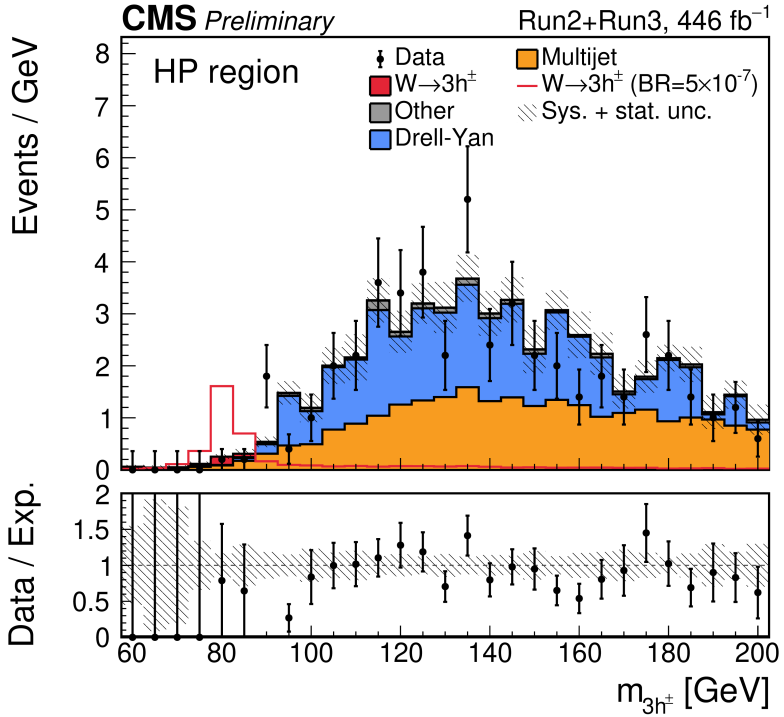


CMS-DP-2026-027

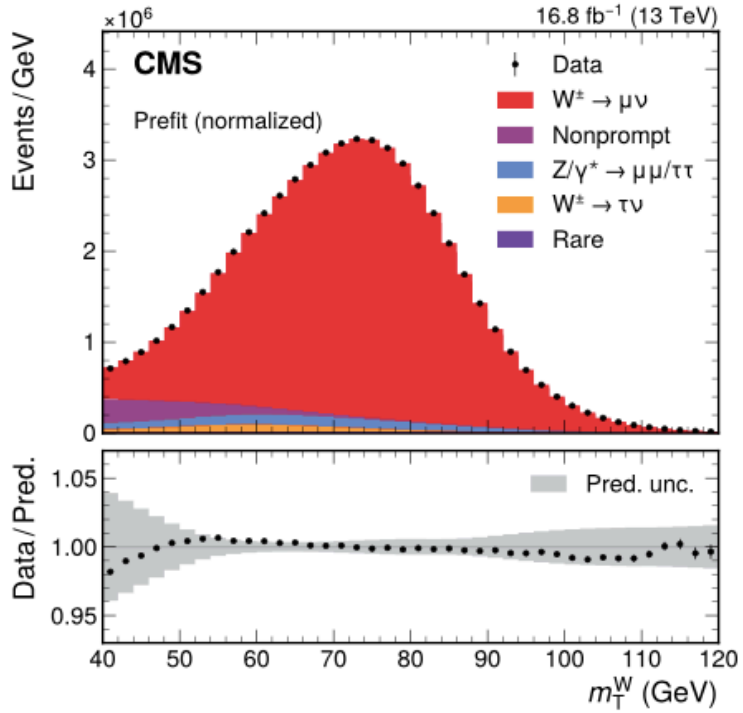


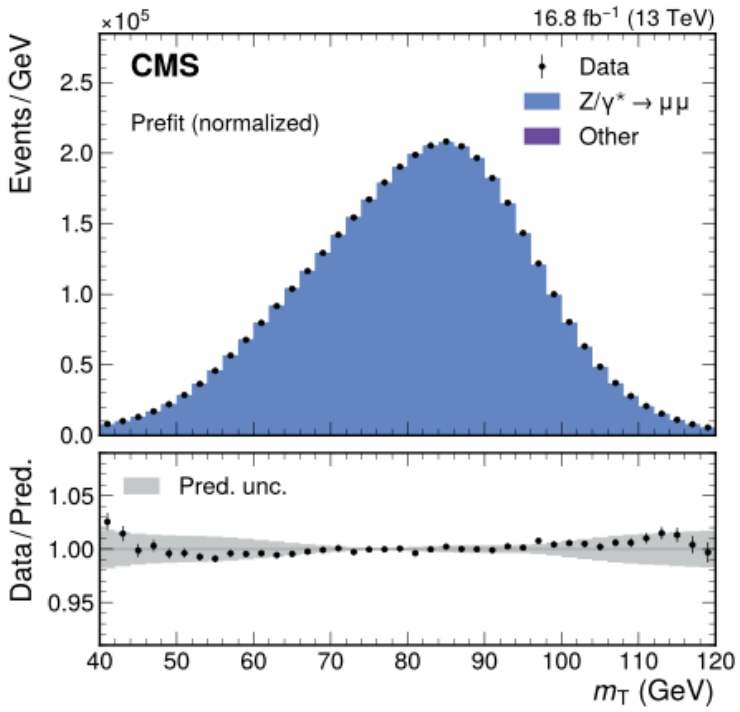
Standard Model: W boson measurements

CMS-PAS-SMP-25-011



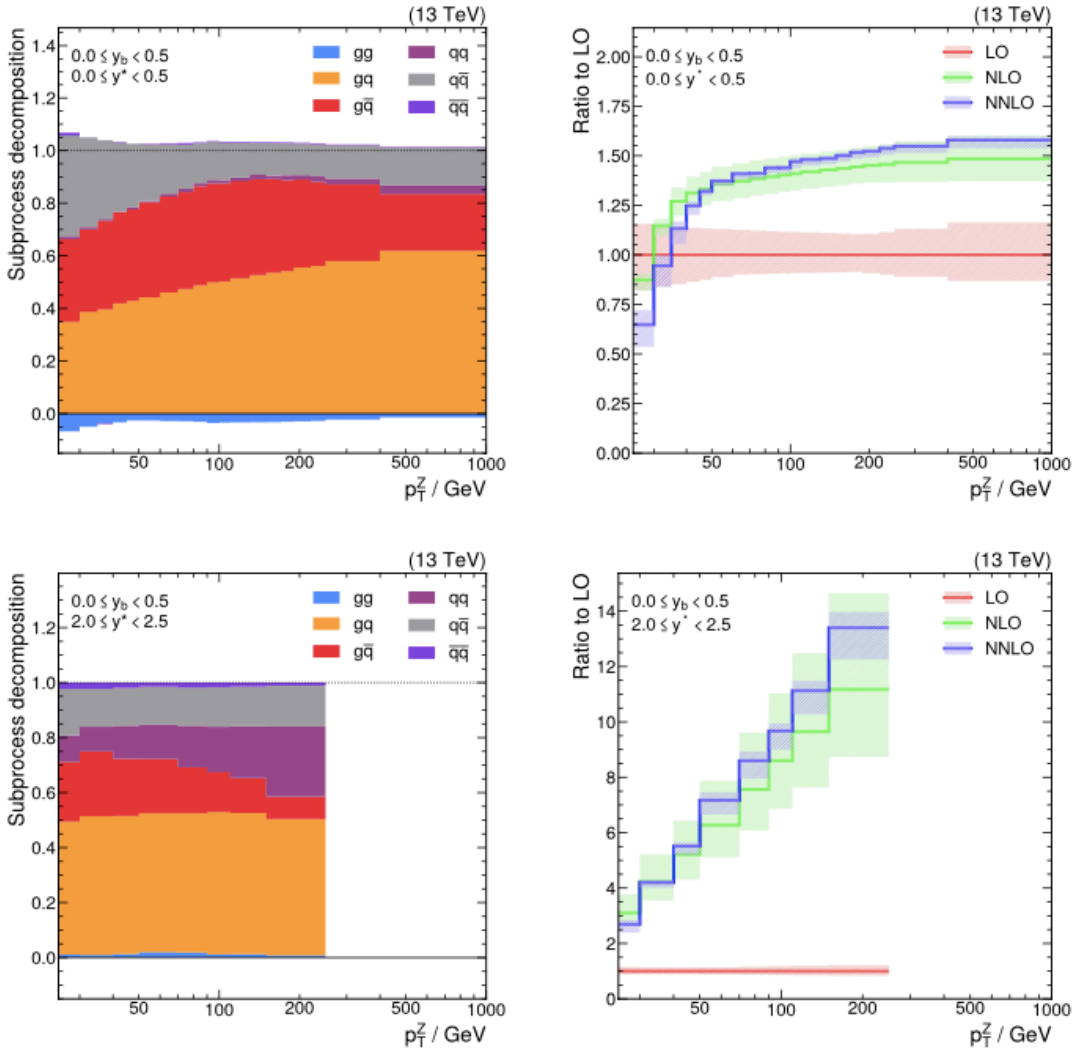
Nature 652, 321–327 (2026)



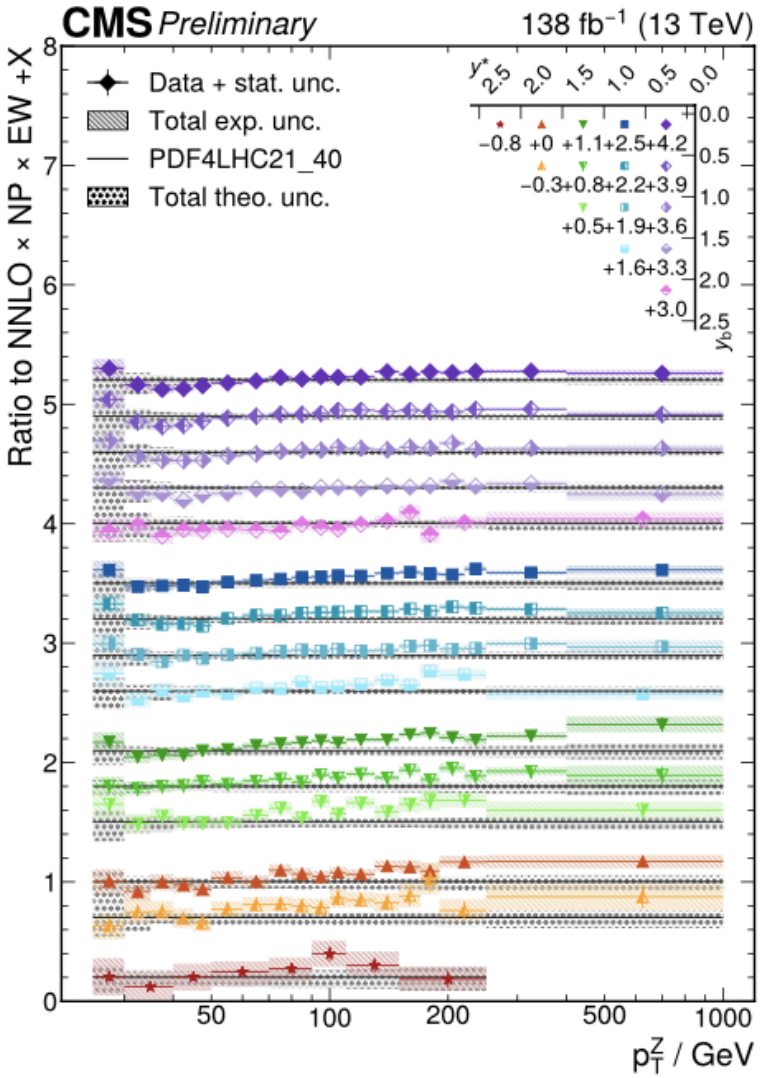


Standard Model: Triple Differential Z+Jets cross section

CMS PAS SMP-24-010

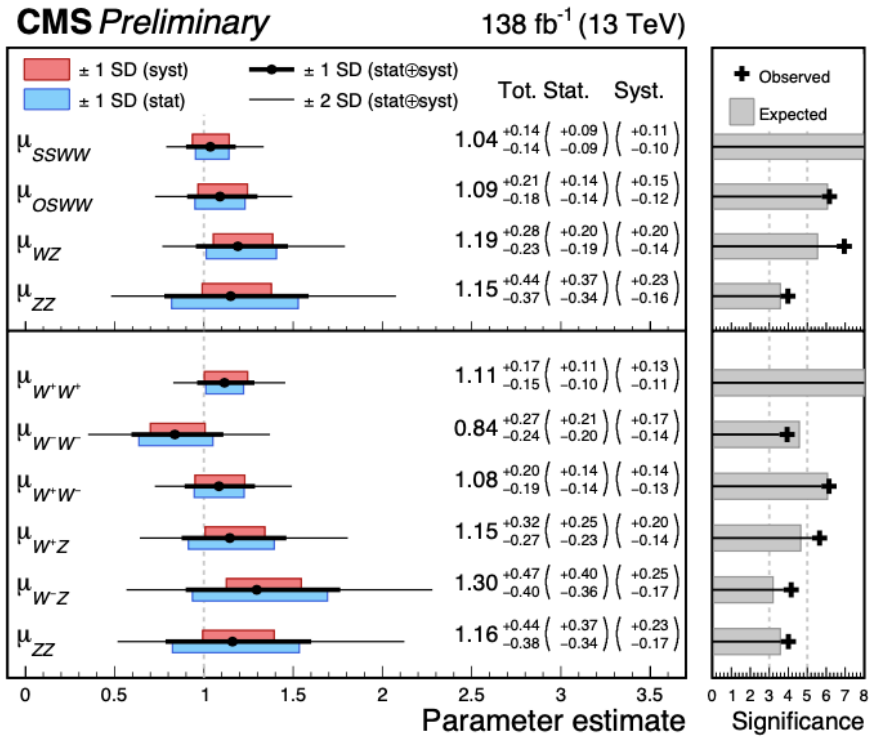


CMS PAS SMP-24-010

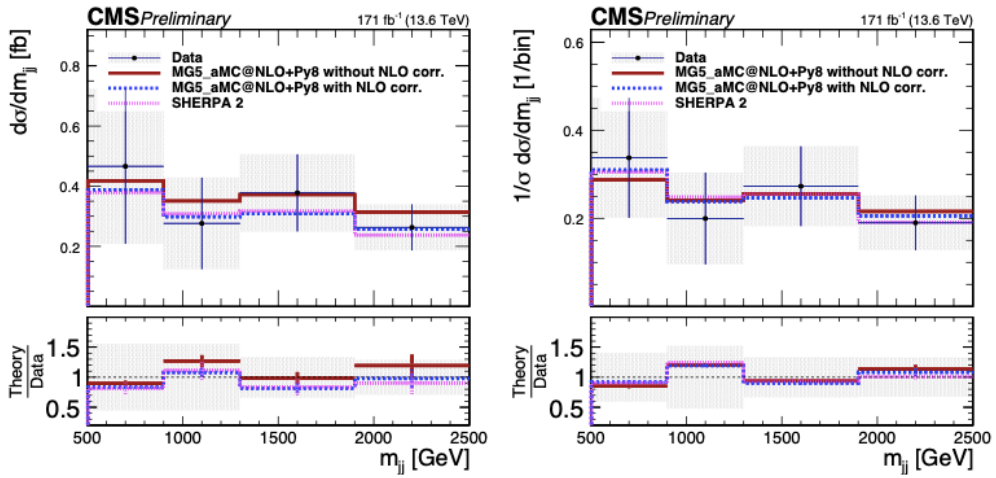


Standard Model: Vector boson & lepton-lepton scattering

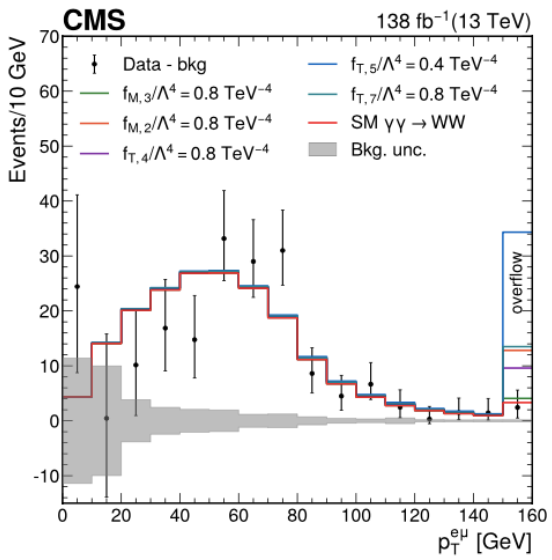
CMS PAS SMP-24-013



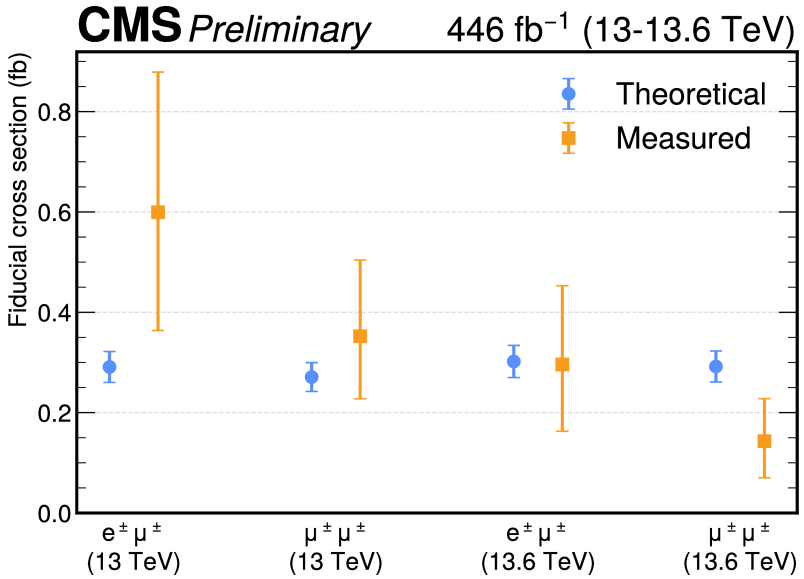
CMS-SMP-25-013



JHEP 06 (2026) 187

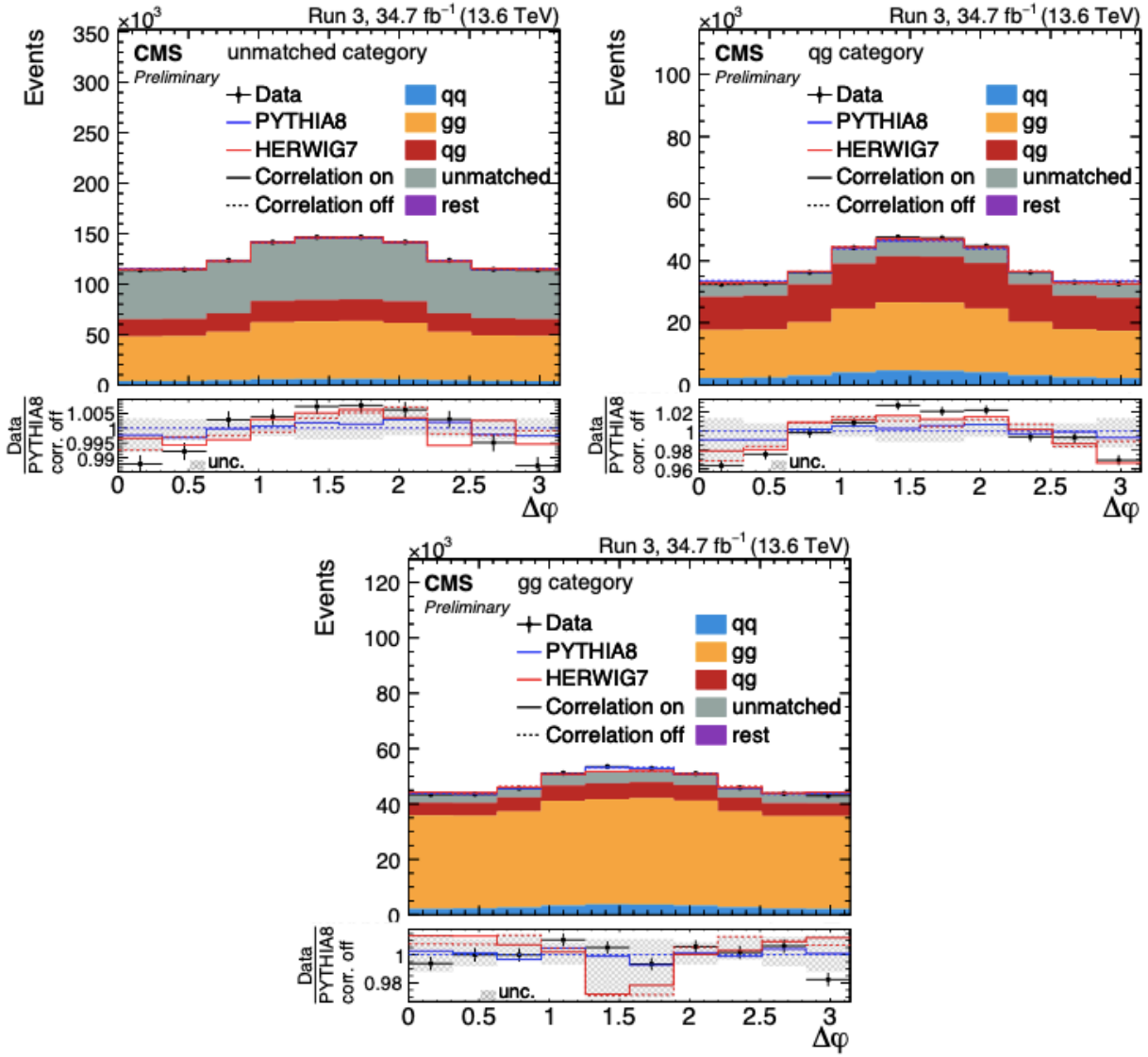


CMS-SMP-26-008



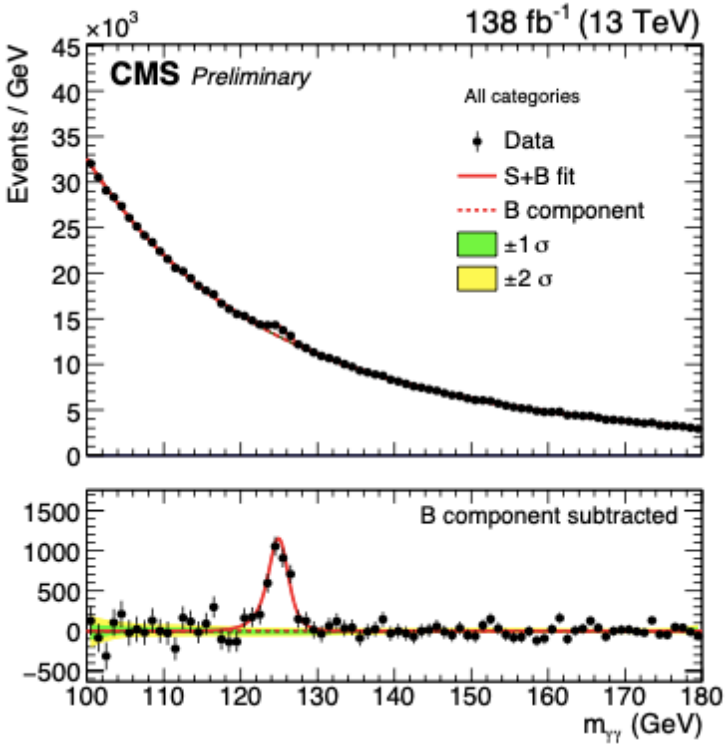
Standard Model: Gluon spin correlation inside jets

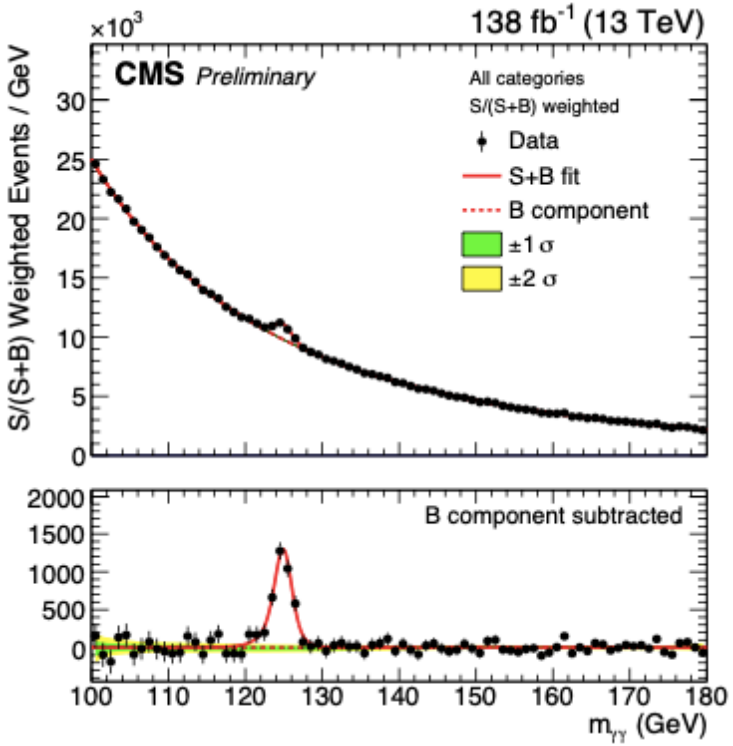
CMS-PAS-SMP-25-006



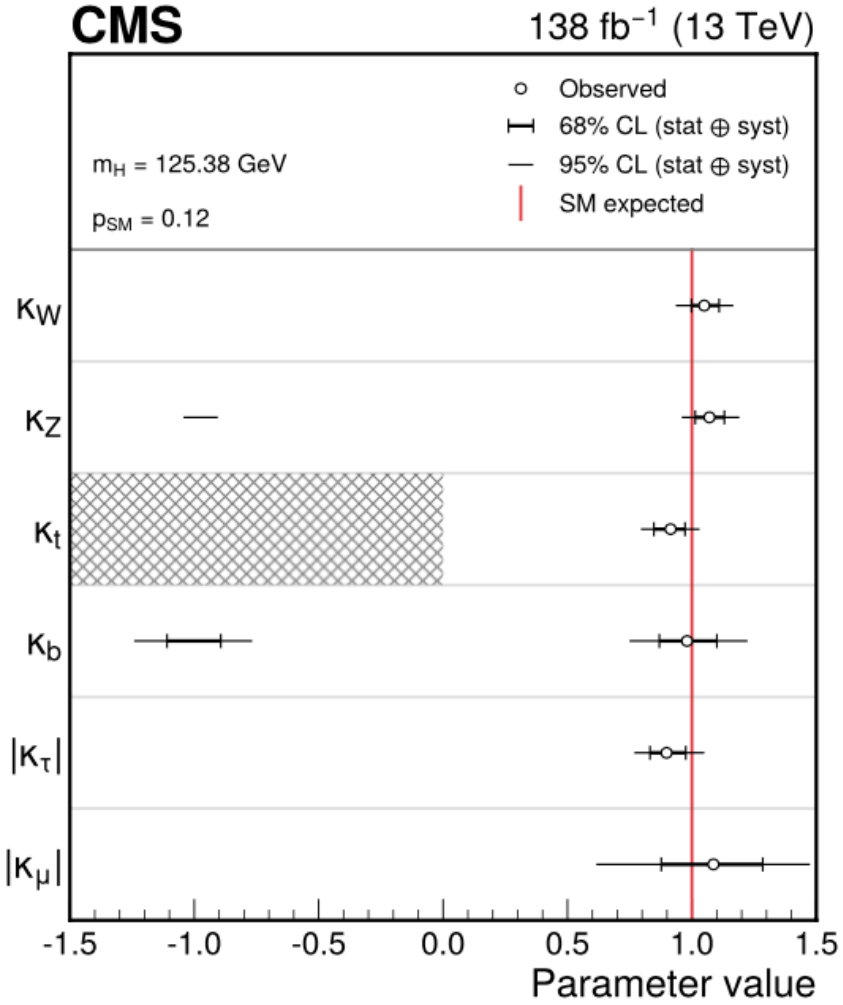
Higgs physics: Precision measurements and couplings

CMS-PAS-HIG-24-007



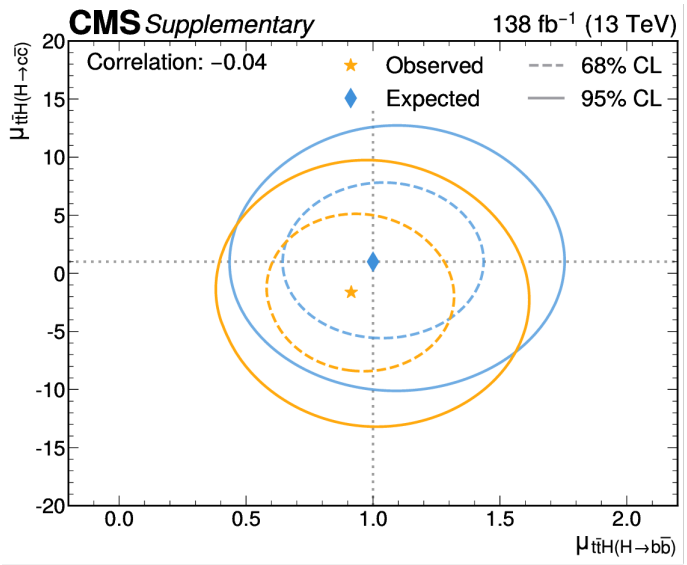


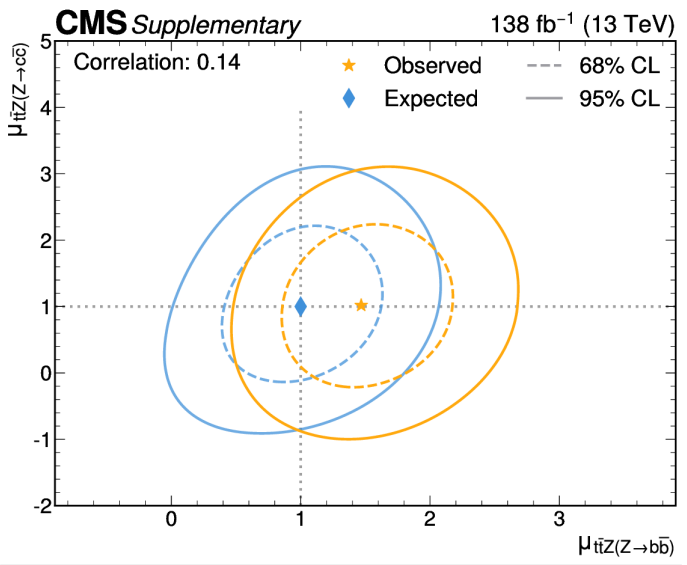
Rep. Prog. Phys. 89 (2026) 087801

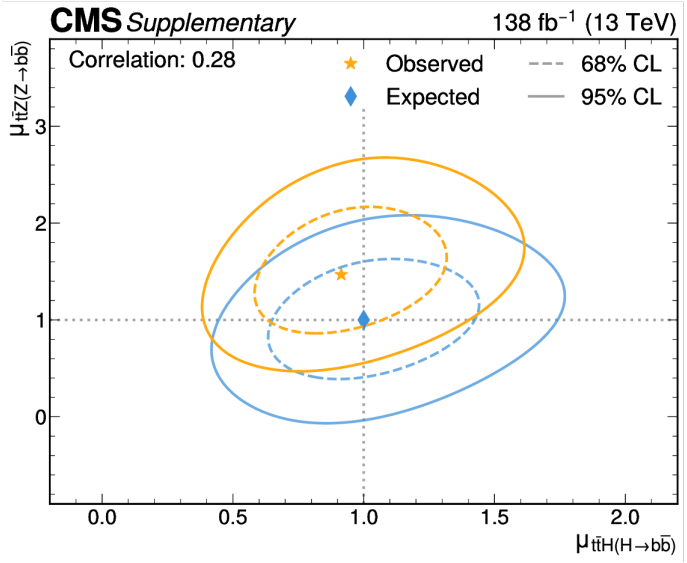


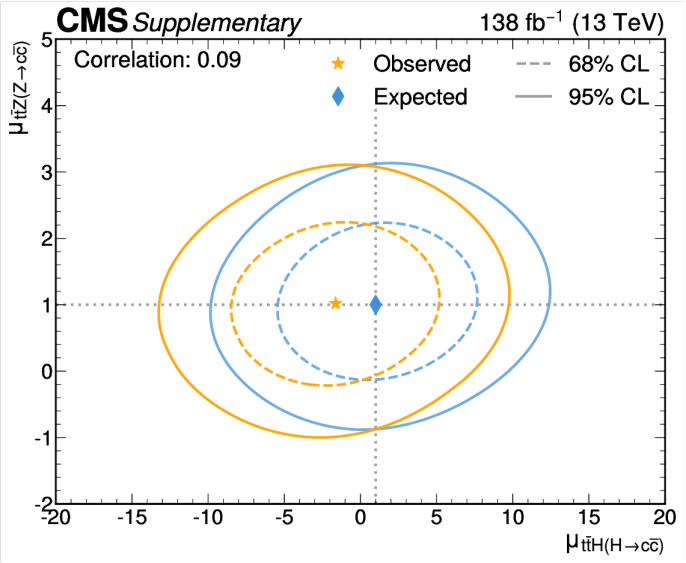
Higgs physics: coupling to charm quark

CMS-HIG-24-018



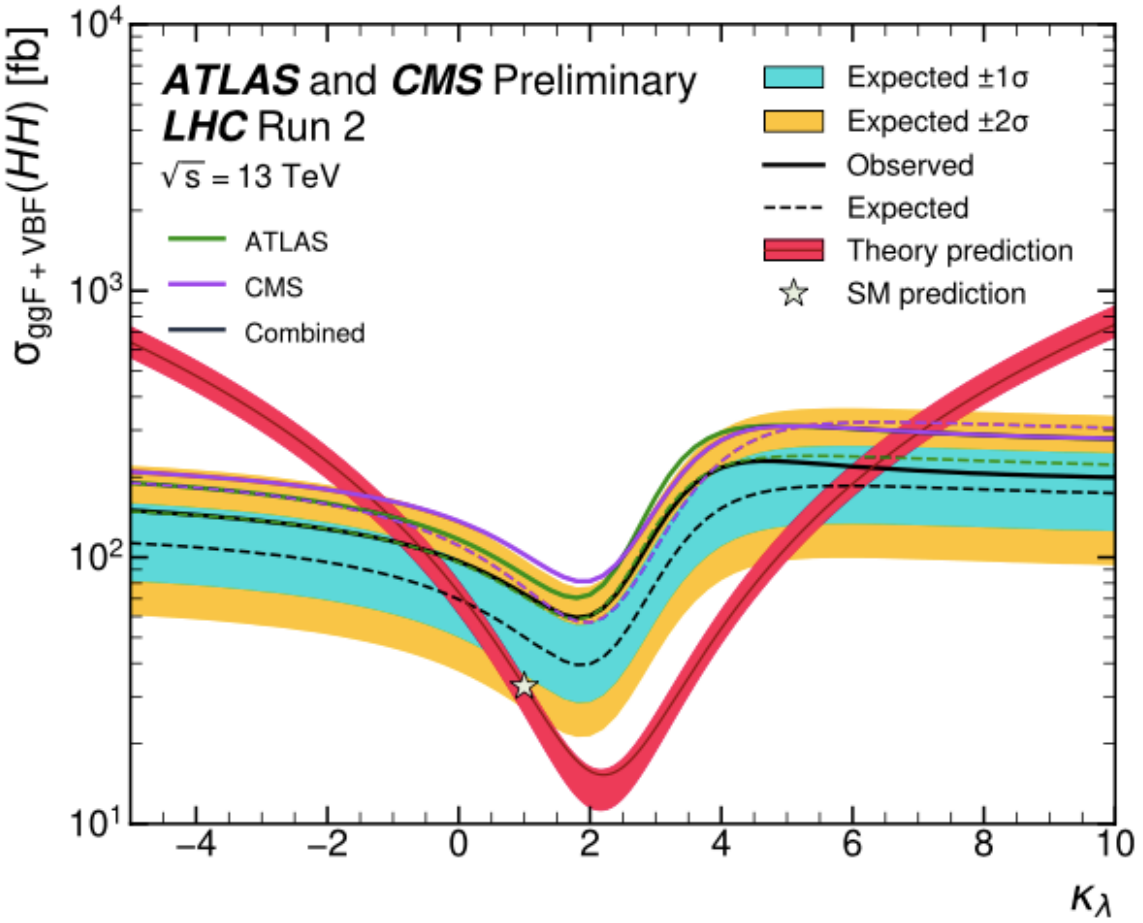




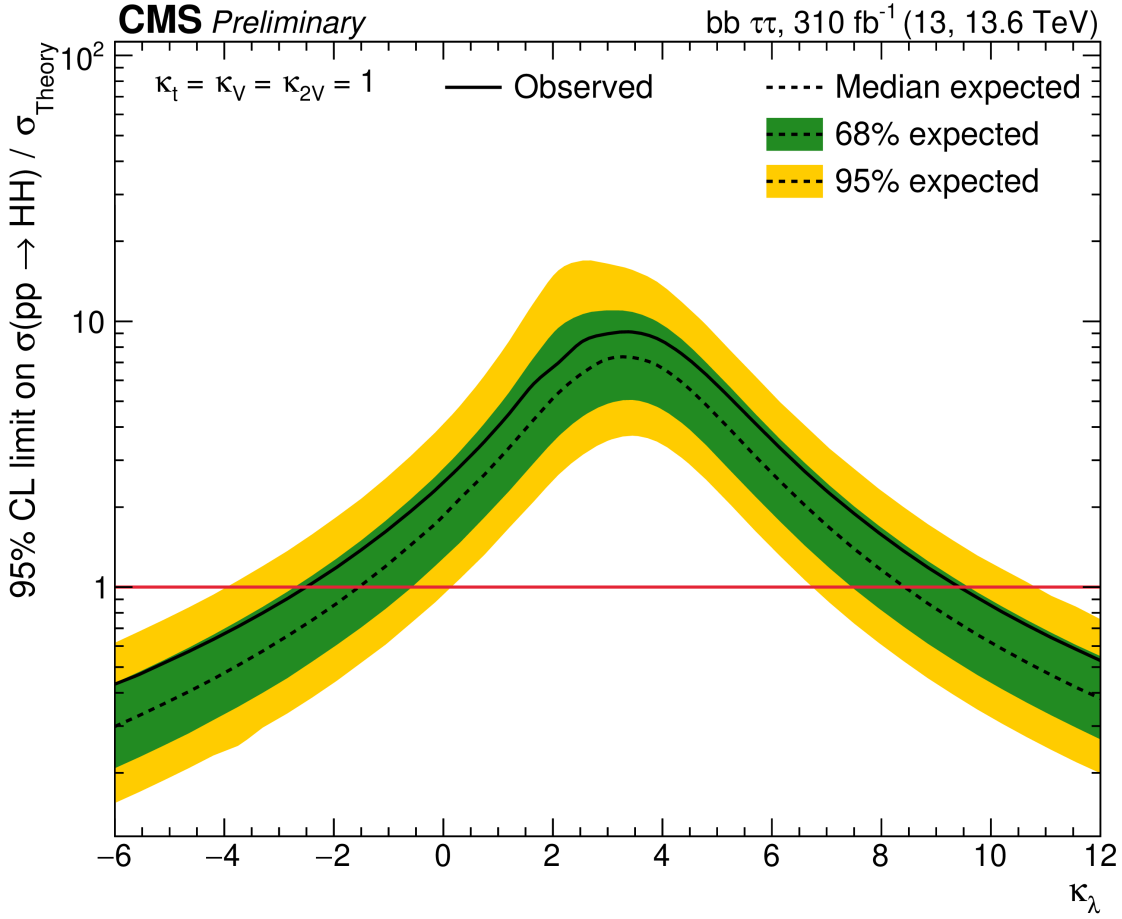


Higgs physics: HH production – from Run 2 to Run 3

CMS PAS HIG-25-014

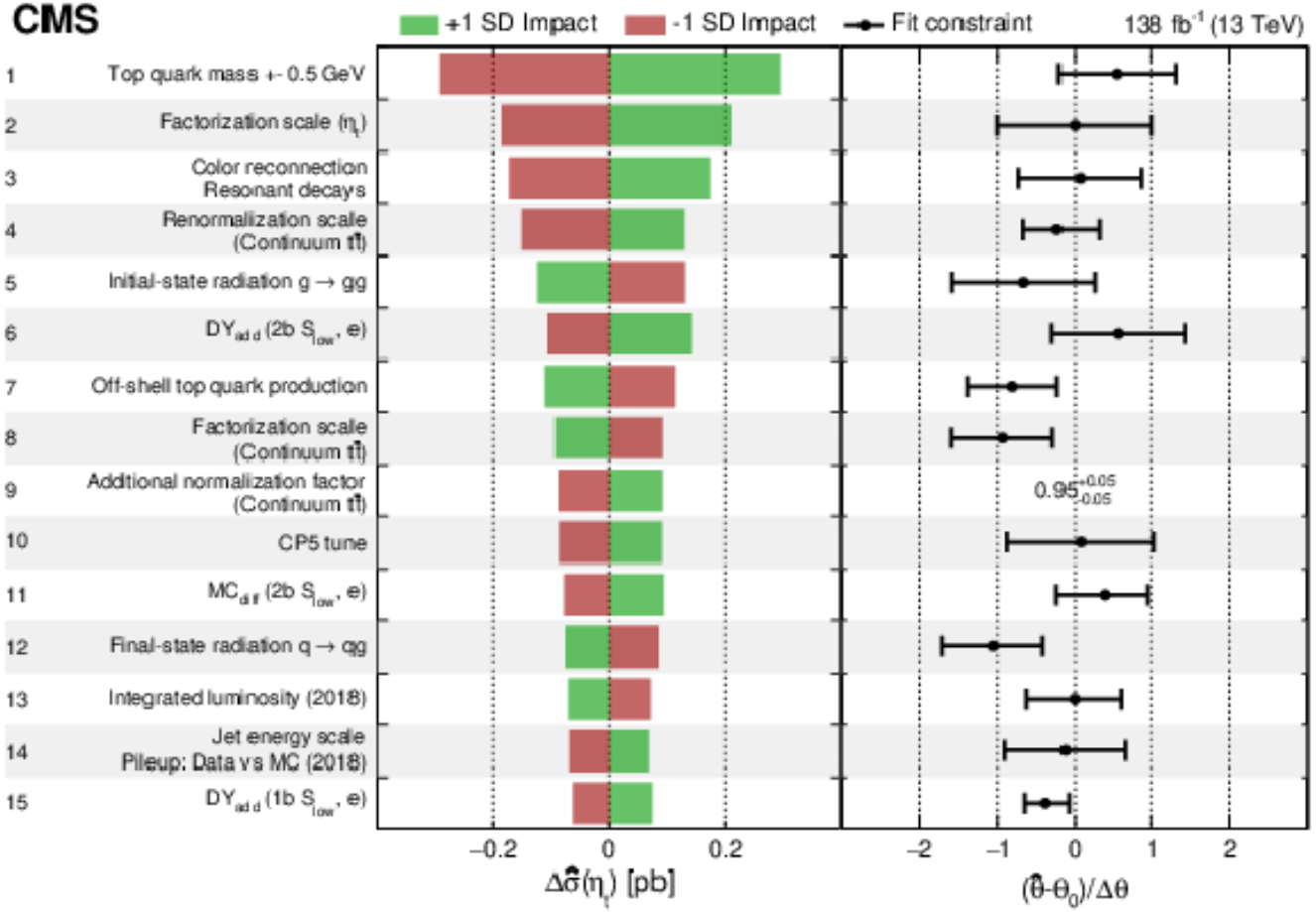


CMS-PAS-HIG-25-008

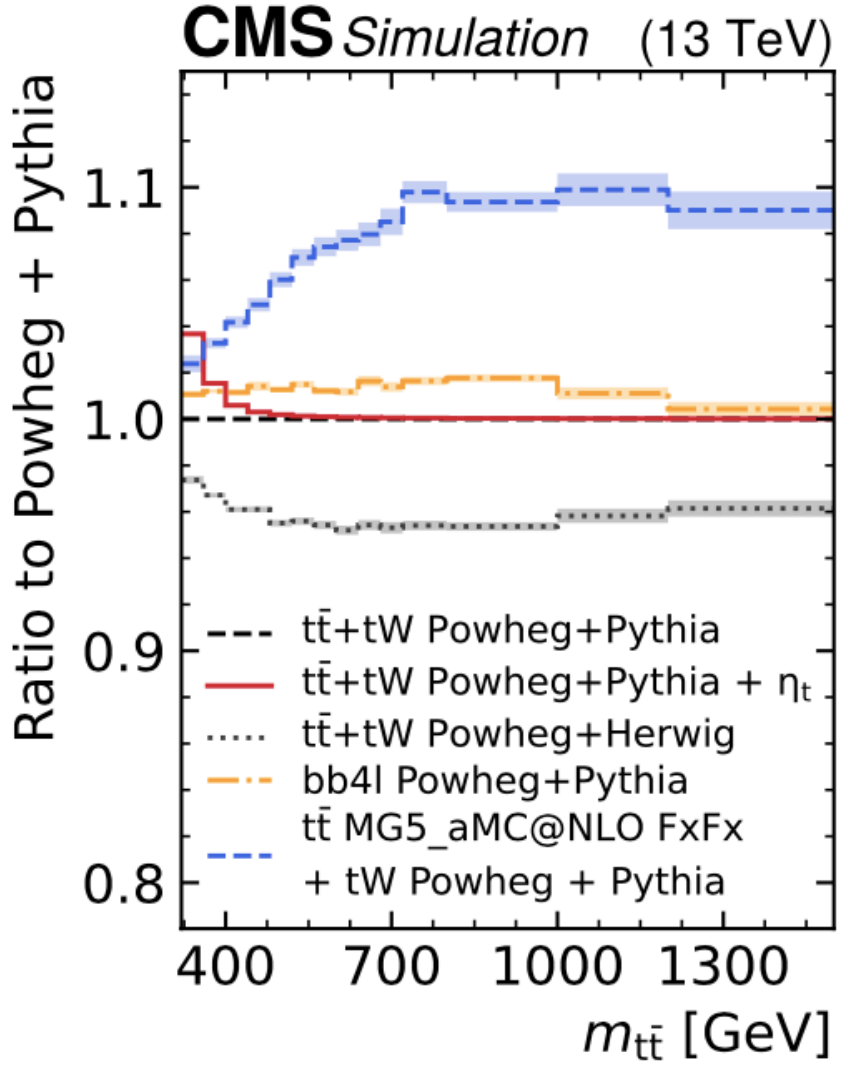


Top physics: excess in ttbar production at threshold

Submitted to Reports on Progress in Physics

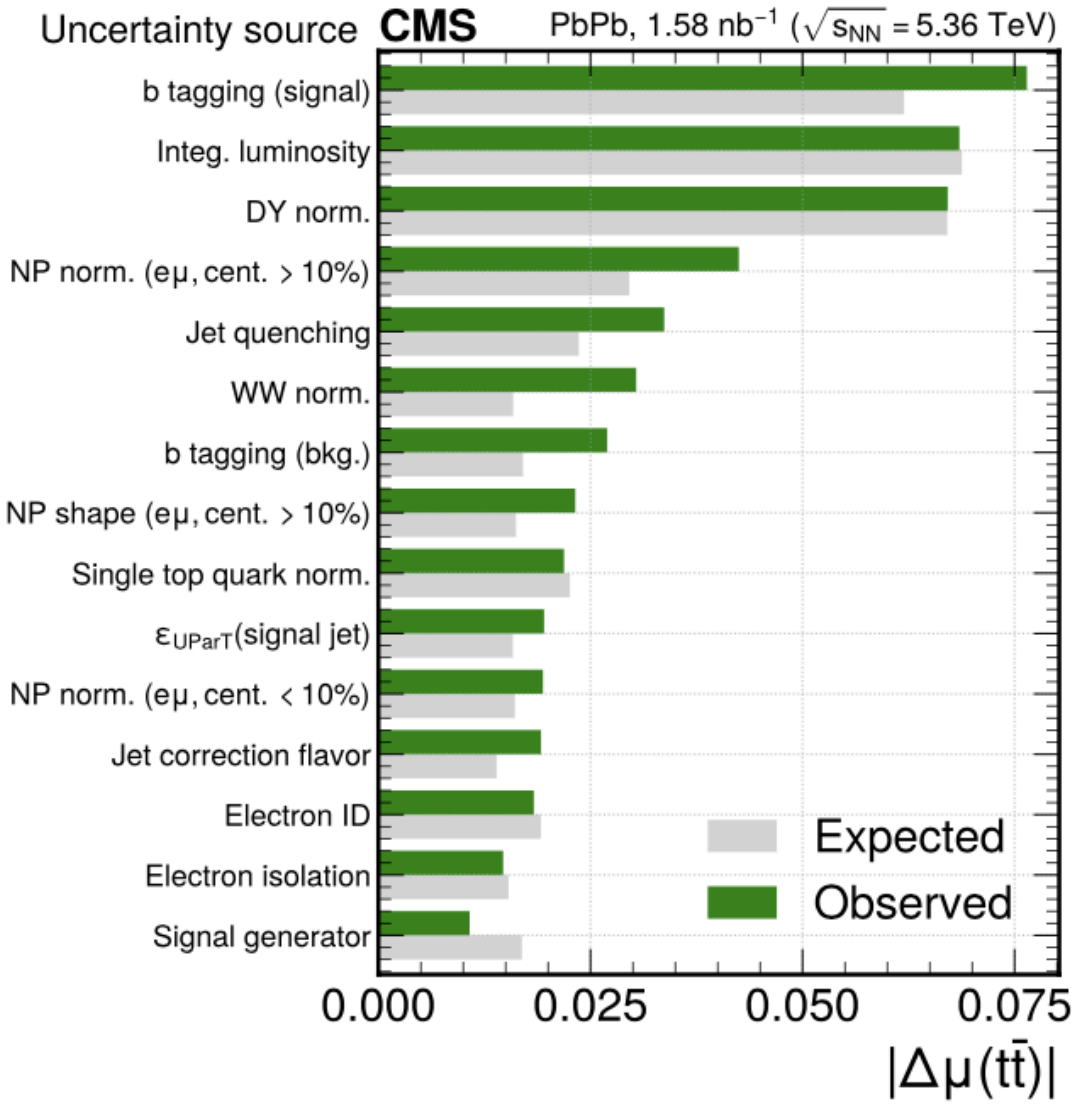


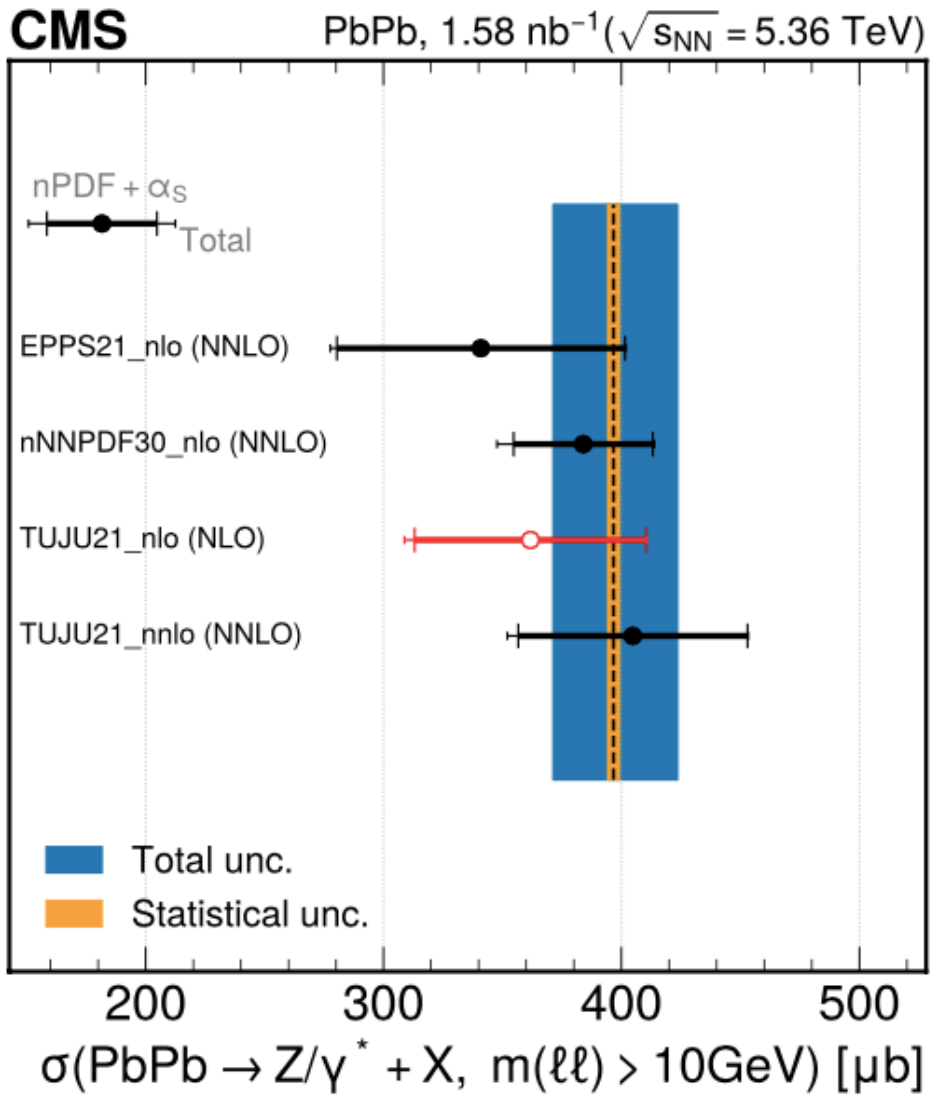
Rep. Prog. Phys, 88 (2025) 087801



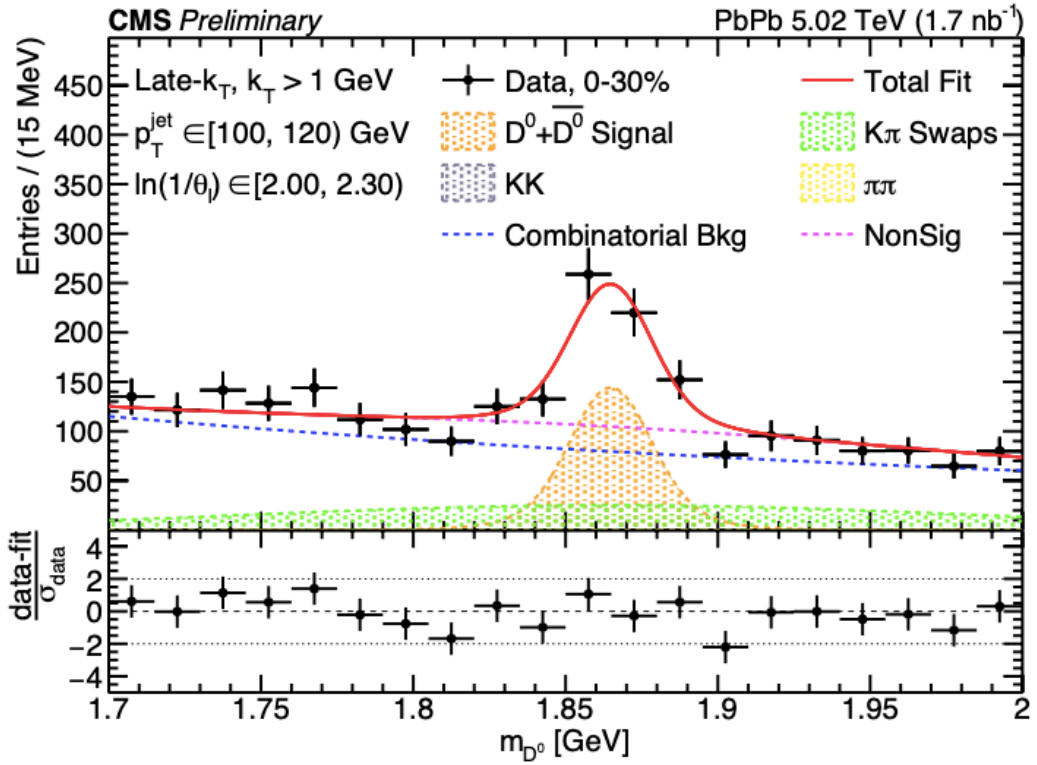
Top/HIN physics: top quark pairs in PbPb

JHEP 08 (2026) 054





HIN physics: dead cone of charm quarks in PbPb



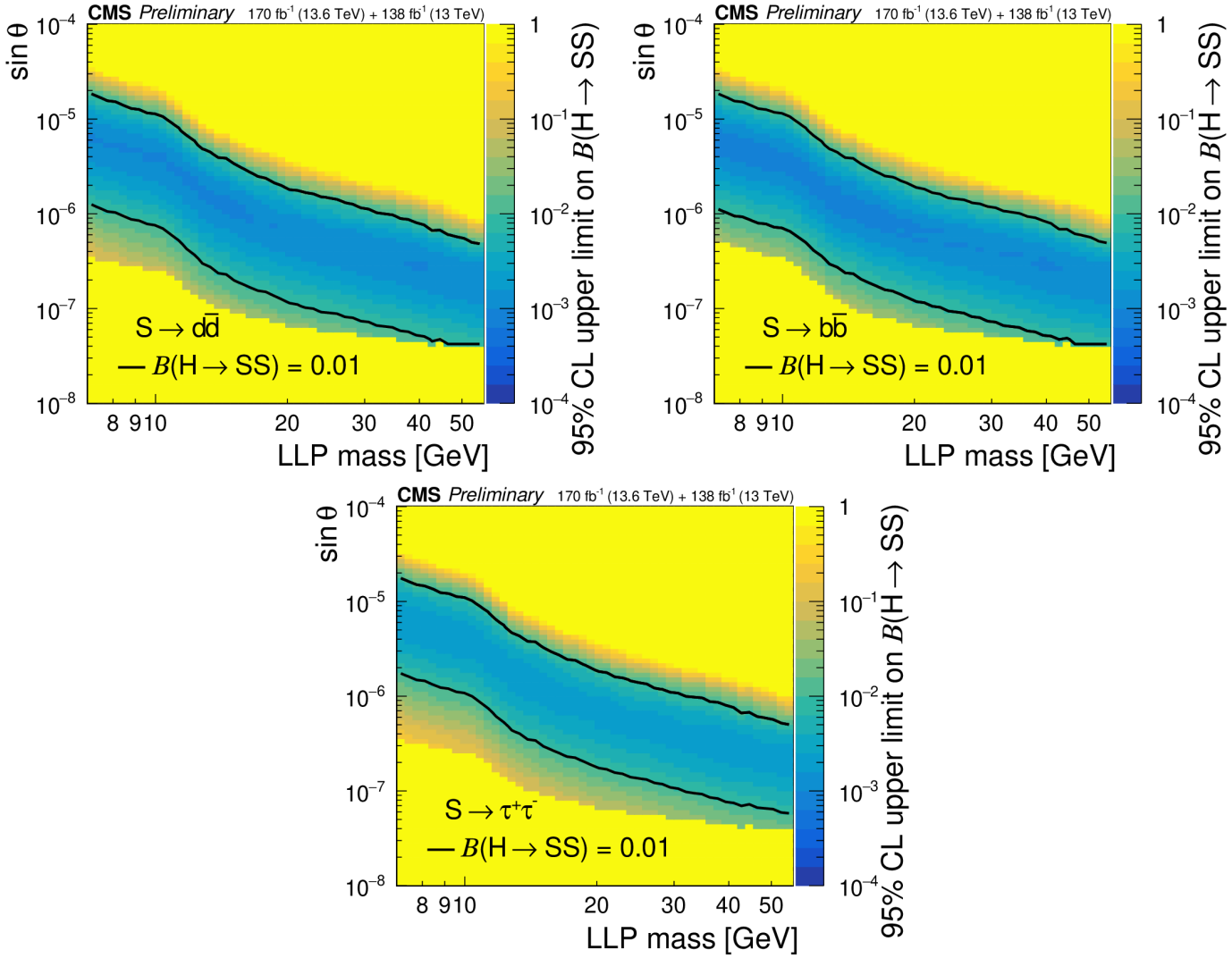
CMS-PAS-HIN-25-013

Table 1: Summary of systematic uncertainties (relative) in each bin of $\ln(1/\theta_l)$ in percent for prompt D^0-tagged jets.

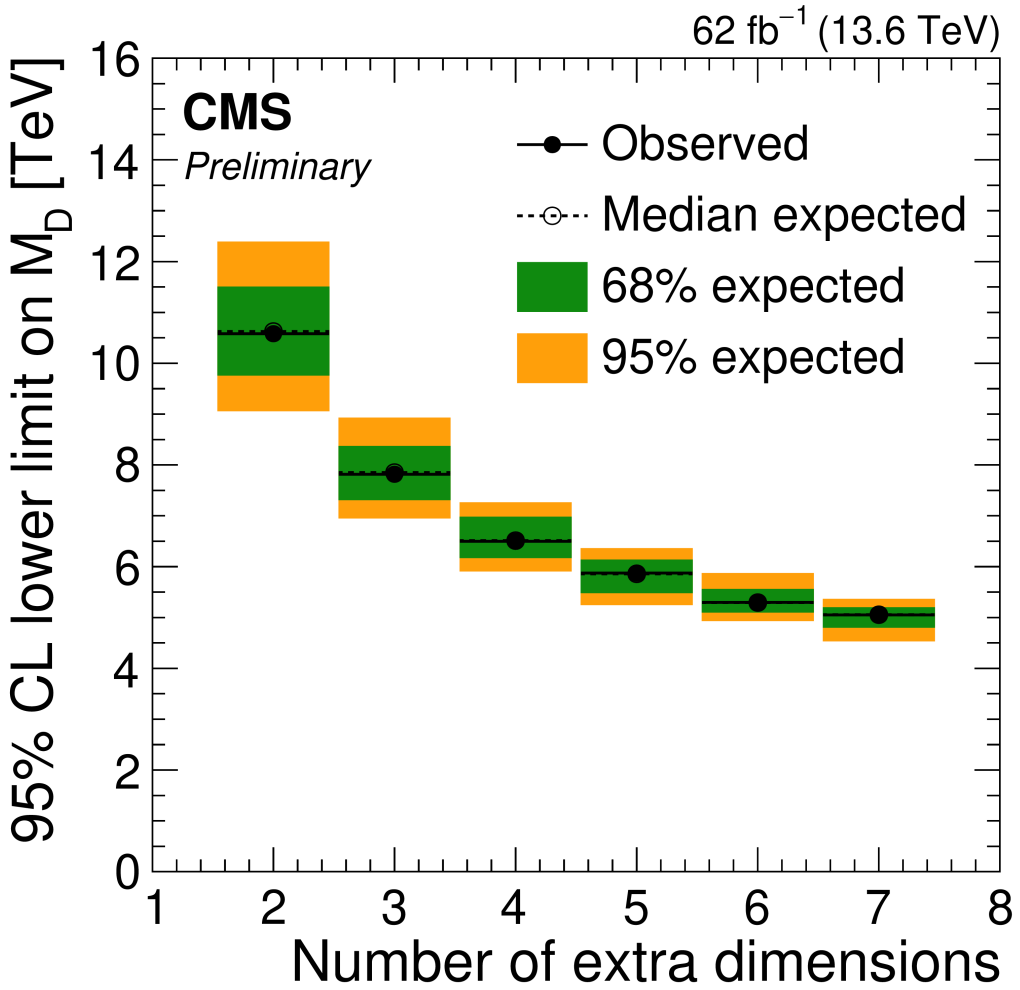
Uncertainty source	$\ln(1/\theta_l)$ [%]			
	1.6–2	2–2.3	2.3–2.55	2.55–3
Jet energy scale	6.0	2.4	3.5	5.1
Jet energy resolution	4.1	1.8	2.9	1.6
Particle Flow scale	2.9	8.9	2.0	10.6
Response matrix statistical	0.2	0.4	2.1	1.1
Tracking	0.3	0.2	0.03	0.4
Physics model dependence	1.3	1.2	3.5	2.8
Signal extraction	8.0	0.3	4.8	1.9
Background modeling	5.1	4.4	2.2	5.8
Prompt fraction	6.2	13.8	2.0	16.6
Total systematic	13.8	17.3	8.6	21.5
Total statistical	16.5	17.4	20.5	19.6

Searches for invisible or long-lived particles

CMS-PAS-EXO-25-005

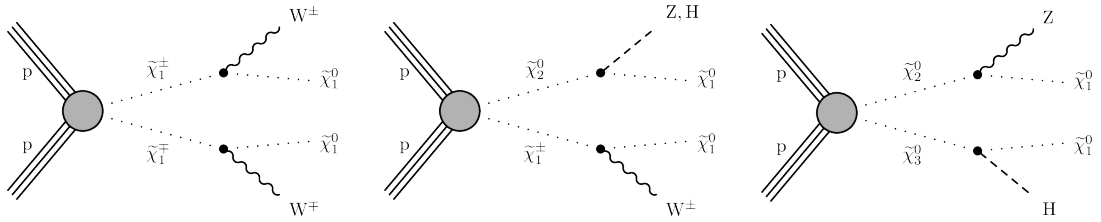


CMS-PAS-NPS-25-008

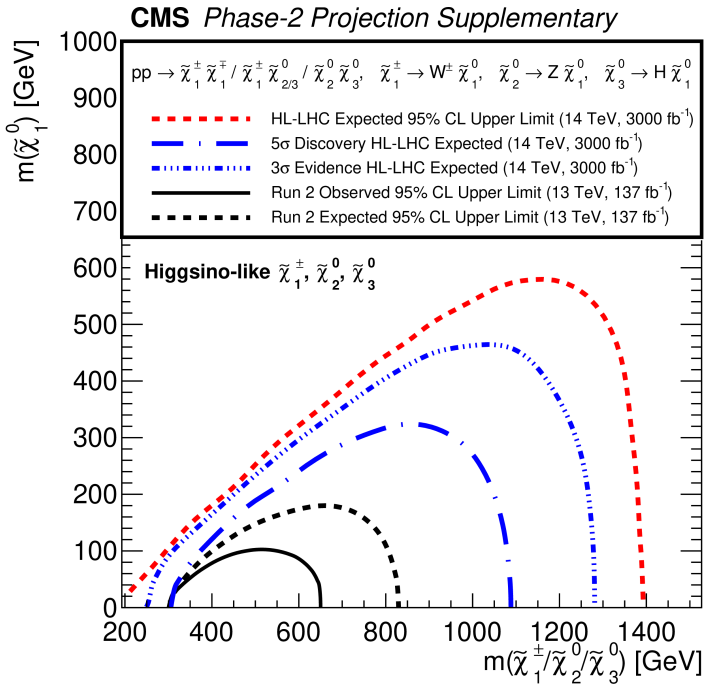


EWK chargino/neutralino search in WW, WZ, WH + MET

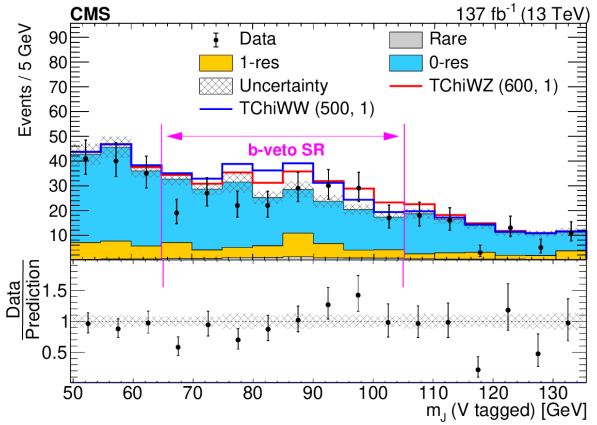
- Search for the direct production of charginos and neutralinos via electroweak interactions

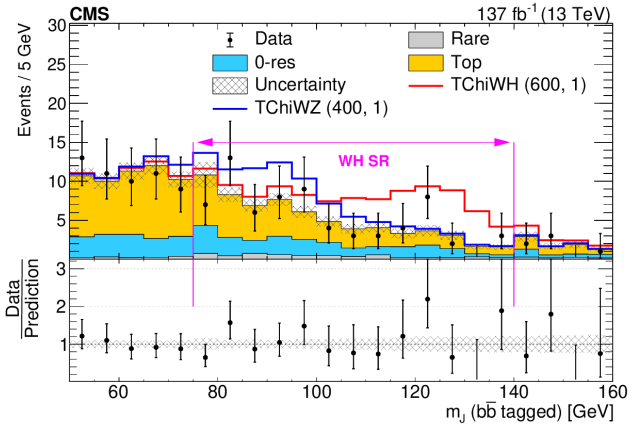


- Hadronically decaying WW, WZ, and WH



Phys. Lett. B 842 (2023) 137460





- Projected 95% CL exclusion for $3ab^{-1}$, for mass-degenerate higgsino-like production functions of the NLSP & LSP mass, compared to results from LHC Run 2 with 137 fb^{-1} of data