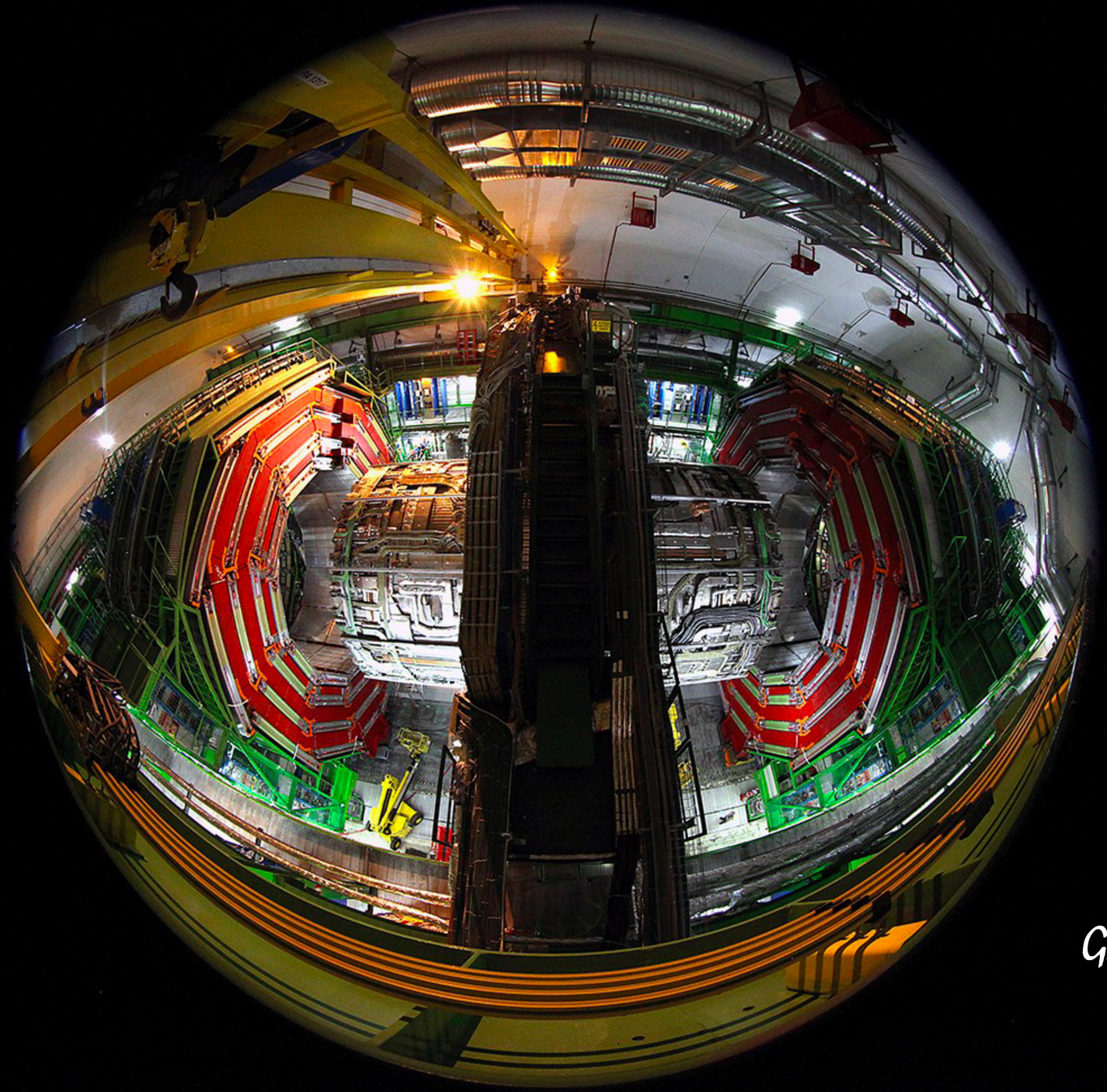


Highlights
and perspectives
from the
CMS
experiment

Gautier Hamel de Monchenault

CEA – Saclay

LHCP

Monday June 7, 2021

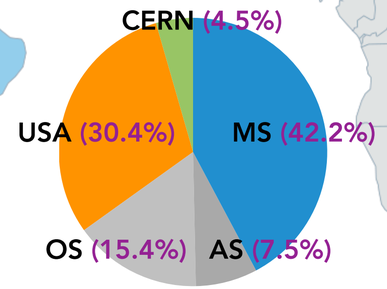
The CMS Collaboration

(May 2021)

2105 Authors

>5300 Members

241 Institutes
(including 23 Associated and 8 Cooperating)
from
54 Countries



1881 PhD Physicists (18% ♀)
1031 PhD Students (23% ♀)
971 Undergraduate Students (26% ♀)
1024 Engineers (12% ♀)

MS: **Italy** (12%), **Germany** (8%), UK (3%), France (3%), Switzerland (3%), Spain (3%), Belgium (3%) …
AS: India (3%), Turkey (2%) …
OS: **Russia** (5%), Korea (3%), China (2%), …

LS2 Activities

LS2 = Long Shutdown 2 since 2019
Collisions to return mid 2022

Strip tracker
- kept cold to avoid reverse annealing
- currently warm during beam pipe bake-out

HCAL
- completion of Phase-I upgrades

Pixel detector
- replace first barrel layer
- replace all DCDC converters

Magnet
- at room temperature since mid 2020
- maintenance work: free wheel thyristor, cryo-cooling, power, pumps, etc.

Beam pipe
- new version Phase-II design

Muon system
- installation of GE1/1 chambers
- upgrade of CSC FEE to sustain HL-LHC trigger rates
- shielding against neutron background

CT-PPS
- upgrade of RP and moving system

BRIL
- BCM/PLT refit
- new T2 tracker

Civil engineering at P5
- prepare for Phase-II assembly and logistics

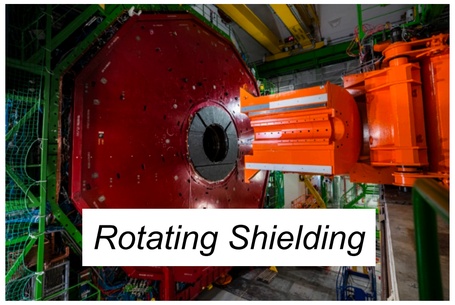
Work on HCAL Barrel (SiPM readout) completed in Oct. 2019

Muon critical path completed in Dec. 2020

Beam-pipe installation and bake-out completed in May 2021

Remaining activities:
- pixel detector installation (starting June 22)
- yoke closing (starting July 19)
- magnet restart (3.8T) and tests
- comics runs at ~4T (CRAFT, 24/7)

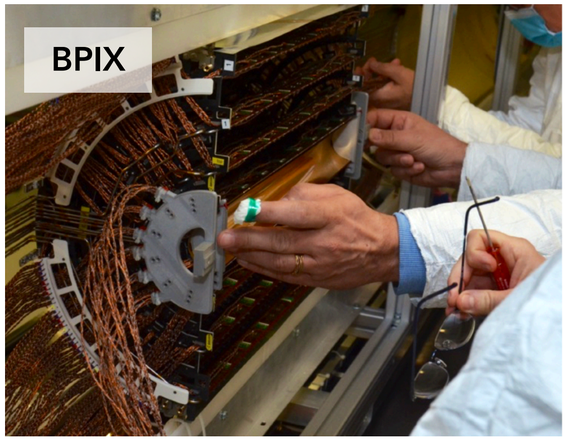
After Pilot Beam Test
- Phase-II muon demonstrators
- new forward shielding


Rotating Shielding

Some Highlights of LS2

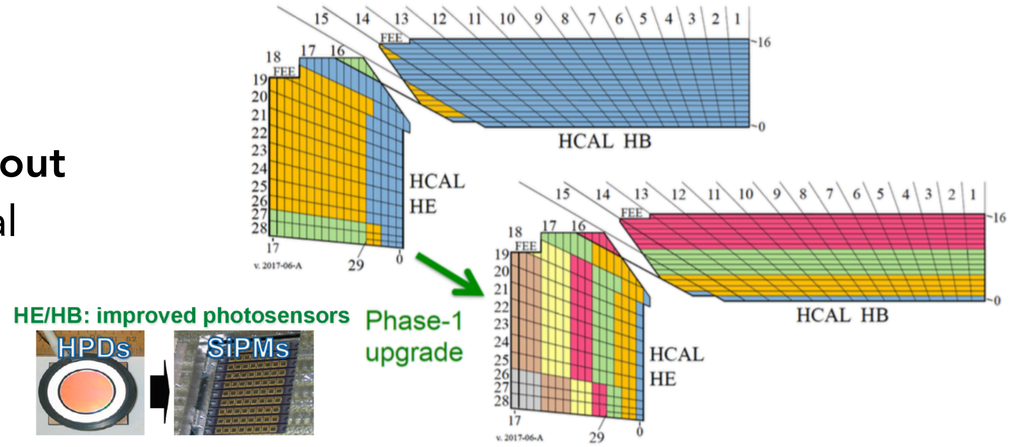
New GEM detector GE1/1
- first Phase-II detector to be integrated in CMS!

New CMS beam pipe for Phase-II
- installation complete, fully aligned and leak tested
- bake-out just completed



Fully-refurbished pixel detector
- new BPIX layer 1: new chip with lower thresholds and better radiation tolerance
- replacement of DCDC converters

New HCAL SiPM readout
- improved longitudinal segmentation
- improved photon detection efficiency

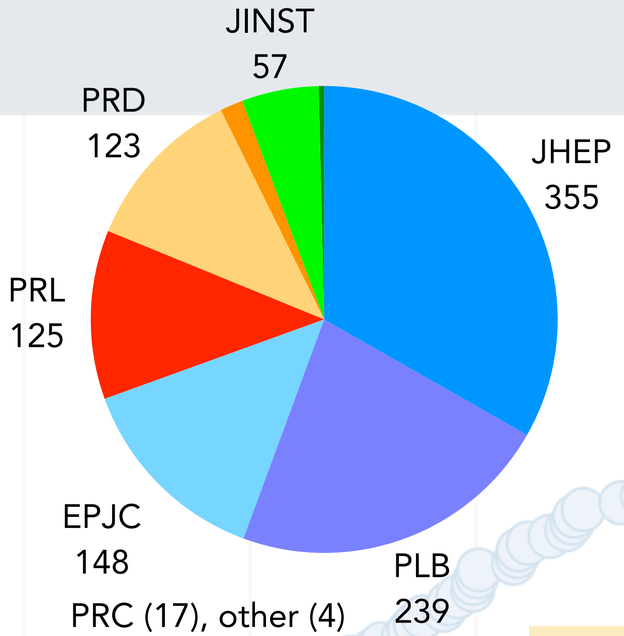


CMS fully on track for the Pilot Beam Test (Oct. 21) and for the start of Run-3 (Feb. 22)

CMS Publications

Phys. Briefing

On Nov. 24, 2020 CMS announced the **publication of its 1000th paper** in a peer-reviewed journal



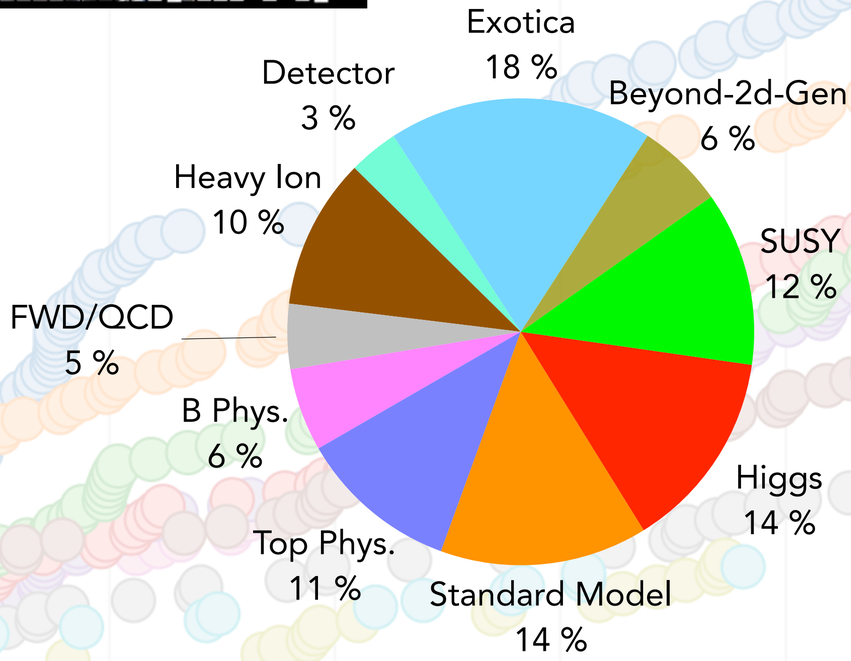
As of June 7, 2021

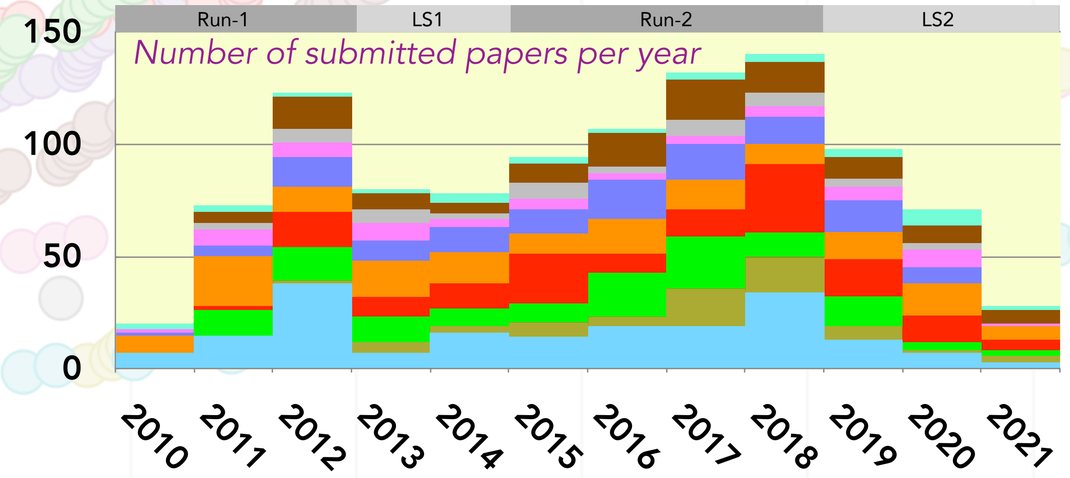
1068 CMS papers
- **1037** published

1043 papers based on **collision data**
- **1012** published
- 574 based on Run-1 data
- 469 based on Run-2 data

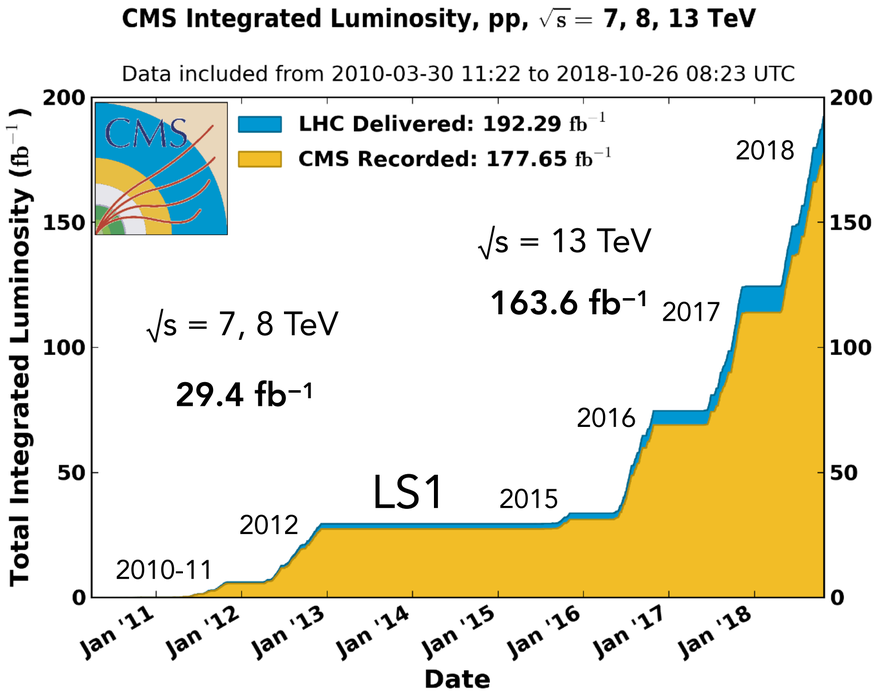
CMS with friends
- **ATLAS**: 5 (4 JHEP, 1 PRL)
- **LHCb**: 1 (Nature)
- **Totem**: 3 (1 JHEP, 2 EPJC)

CMS titles
- 527 "Search for"
- 39 "Observation"
- 18 "Evidence"
- 308 "Measurement"





CMS pp Data at LHC Run-2

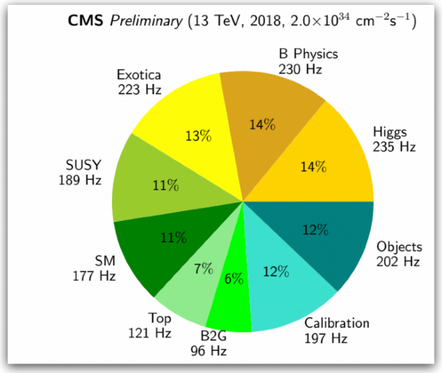


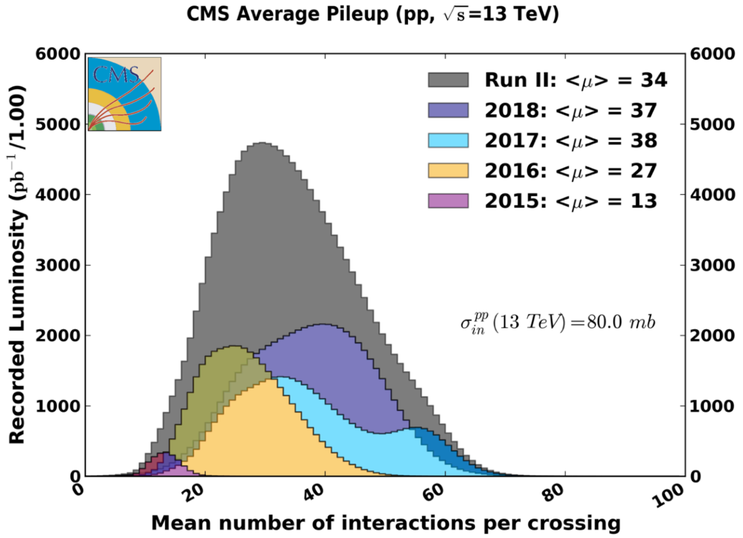
Excellent performance of the LHC in Run-2

- max LHC luminosity (2018):
  $\mathscr{L}_{max} = 2.14 \times 10^{34}\ cm^{-2}s^{-1}$
  (factor of 2 higher than designed $10^{34}\ cm^{-2}s^{-1}$)

CMS Dataset Run-2

- 2016-2018: **137 fb⁻¹** of pp data "good for physics"
- data-taking efficiency > 92% (2018: 94%)
- number of pp interactions per beam crossing (PU): <μ> = 34





CMS Triggers for Run-2 (1.6 kHz)

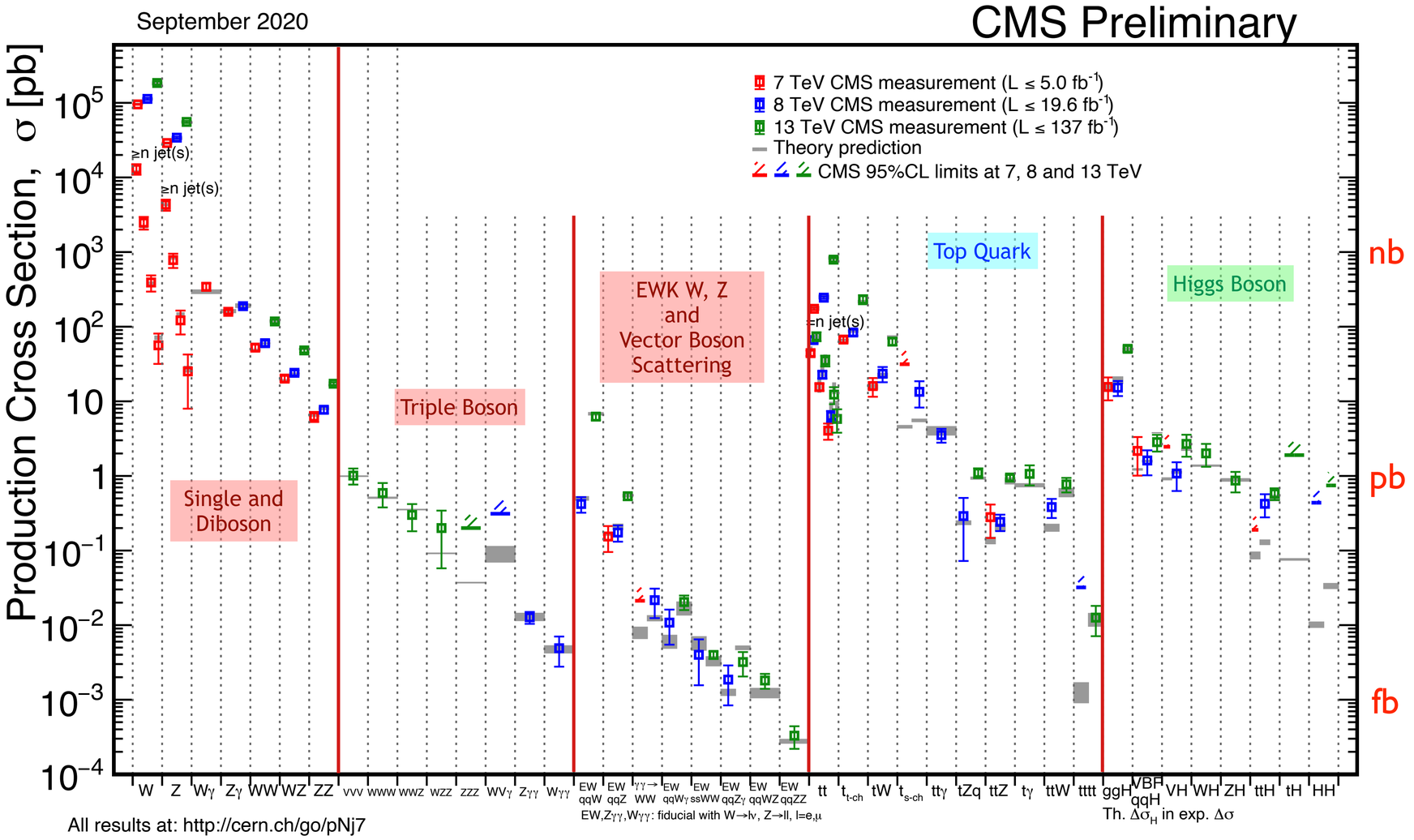
- Standard triggers (leptons, jets, MET)
- **B-parking triggers** (up to 5 kHz)
  10B events enriched in un-biased B decays
- Scouting triggers
  reduced events with physics objects

Luminosity measurements: 1.2% in 2016, overall 1.6% for Run-2

CMS-LUM-17-003
Submitted to EPJC

Phys. Briefing

SM Production Cross Sections



Physics highlights in this talk

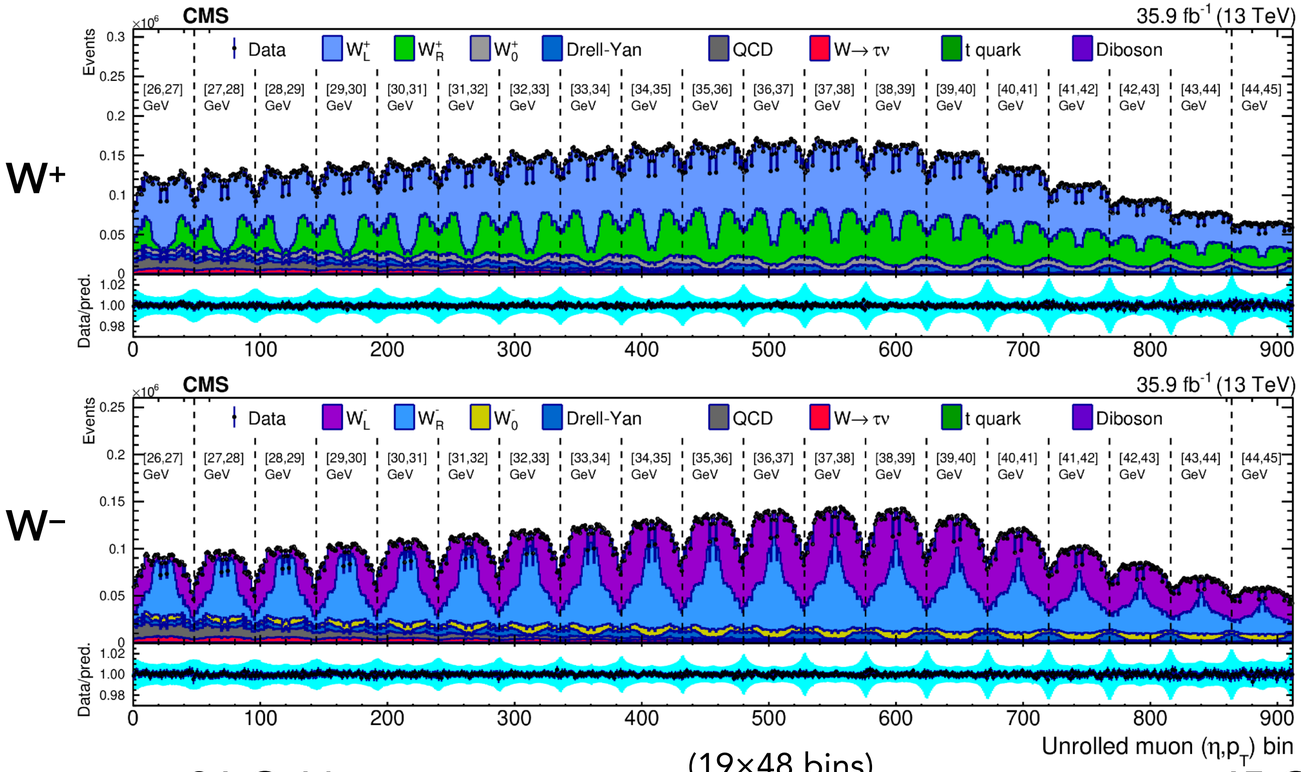
- [Angular anlysis of $B_s \to J/\psi\phi$]
- W helicity and charge asymmetry
- Lepton universality in W decays
- Polarisation in WZ production
- Vector boson scattering
- [Triboson production]
- Higgs mass measurements
- H → γγ, 4ℓ, [ττ,] and STXS
- [Higgs differential cross sections]
- Evidence for H → μμ
- Search for di-Higgs production
- Top-quark mass measurements
- Running of the top-quark mass
- Heavy quarks in HI collisions
- [Jet structure in HI collisions]
- Search for heavy resonances
- [Long-lived particles]

[see backup slides]

W Helicity Measurements

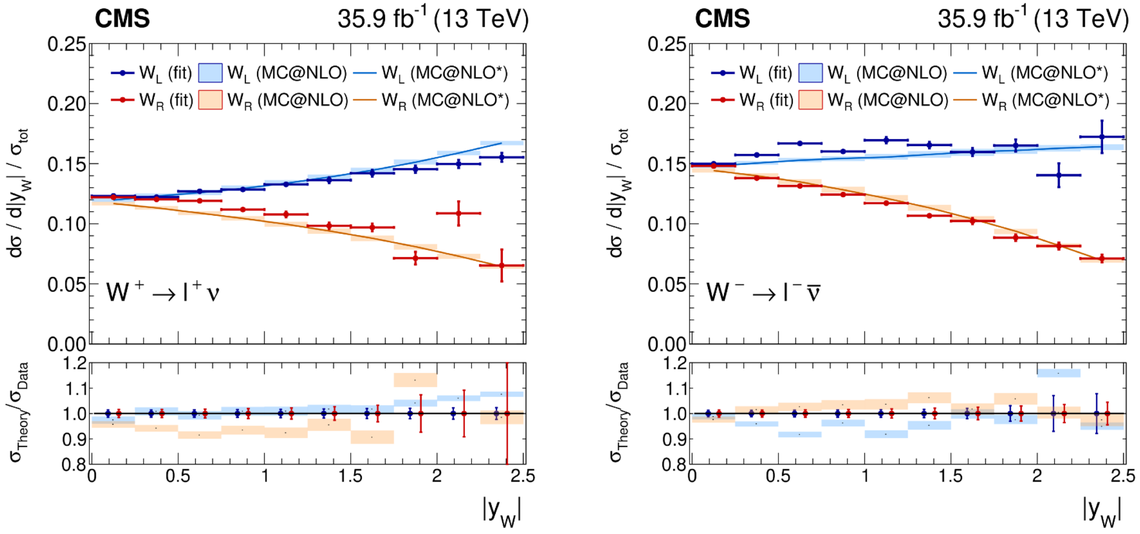
Run-2 2016, 35.9 fb^{-1}

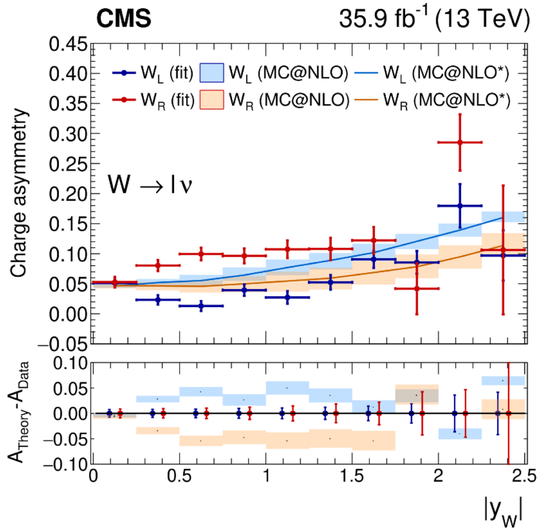
Double-differential cross-sections in p_T^{ℓ} and η^{ℓ} (ℓ = e, μ) for W$^+$ and W$^-$



p_T^{μ} = 26 GeV → 45 GeV (19×48 bins)

$\eta \in [-2.4, 2.4]$





- constraints on PDFs
- milestone towards the W mass measurement

[CMS-SMP-18-012](#)
PRD 102 (2020) 092012

Template fit to extract **differential cross-sections** and **charge asymmetries** for the two **helicity states**

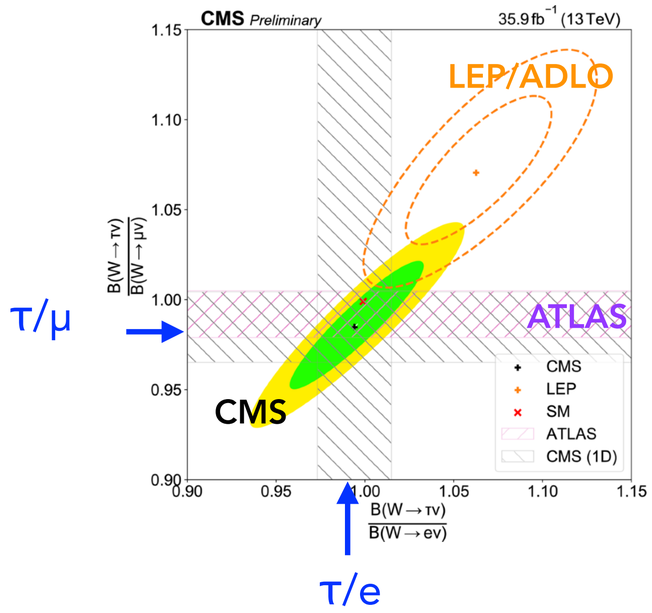
Test of τ/μ and τ/e Universality in W Decays

Using $t\bar{t}$ events in the dilepton channel, select relatively **unbiased samples** **of on-shell W bosons**

Trailing lepton p_T used to discriminate between prompt W → e/μ decays from W → τ → e/μ decays in ee, μμ, and eμ events

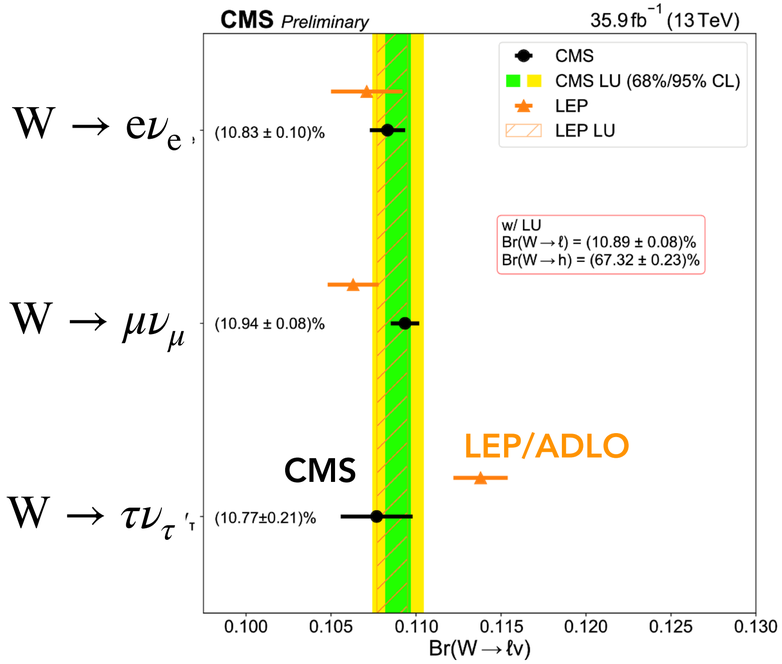
Run-2 2016, 35.9 fb^{-1}

CMS-PAS-SMP-18-011



result consistent with SM and with recent ATLAS (most-precise) τ/μ result

Branching fractions W → e, μ, τ



CMS LU result is consistent with and improves on LEP/ADLO result

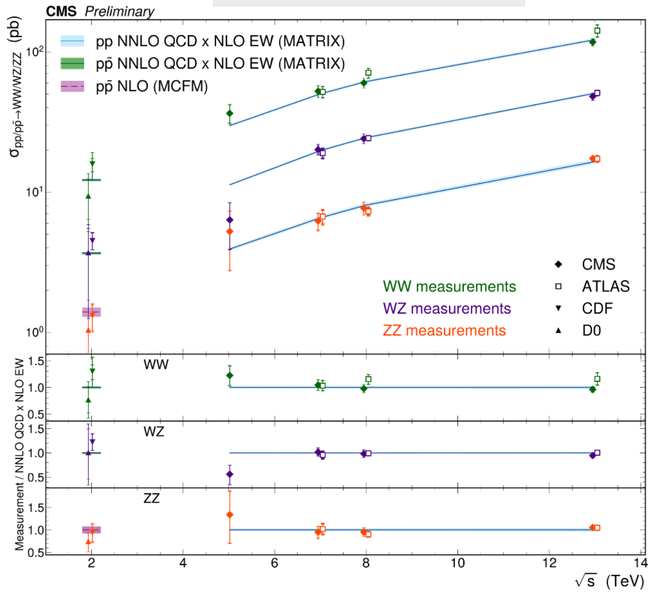
A long-standing LEP "tension" (>2.5σ) is **gone**

Diboson Production

Precision studies of **diboson production**

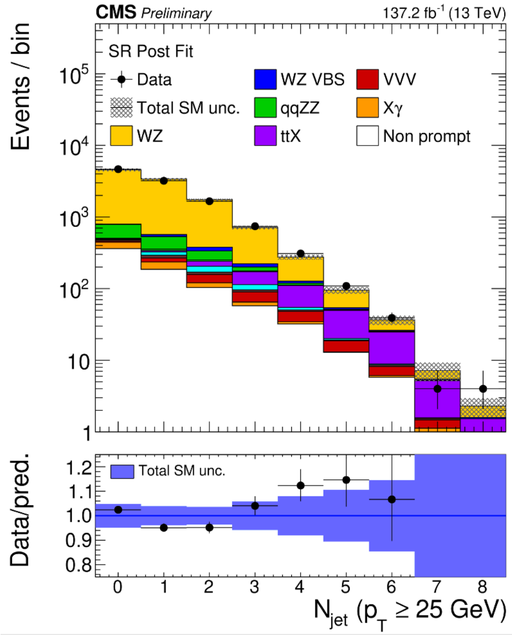
- abundant samples, well-controlled backgrounds
- 3-10% level measurements at $\sqrt{s}$ = 7, 8 and 13 TeV
- a new measurement at $\sqrt{s}$ = 5.02 TeV

CMS-PAS-SMP-20-012

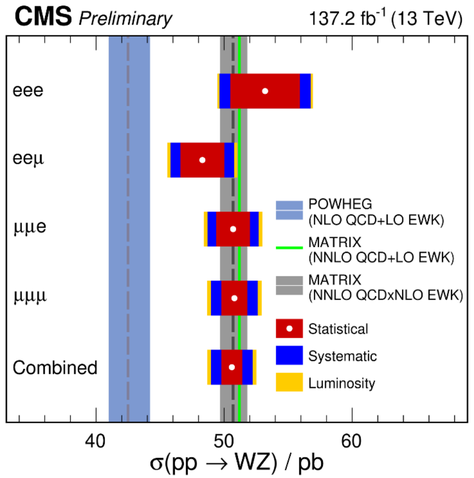


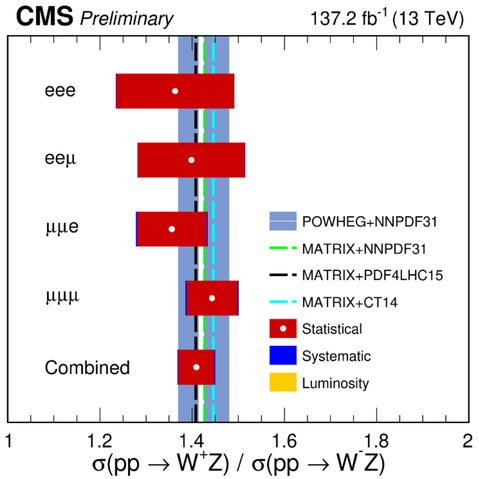
Luminosity uncertainty:
1.9% at $\sqrt{s}$ = 5.02 TeV (302 pb^{-1})

CMS-PAS-LUM-19-001



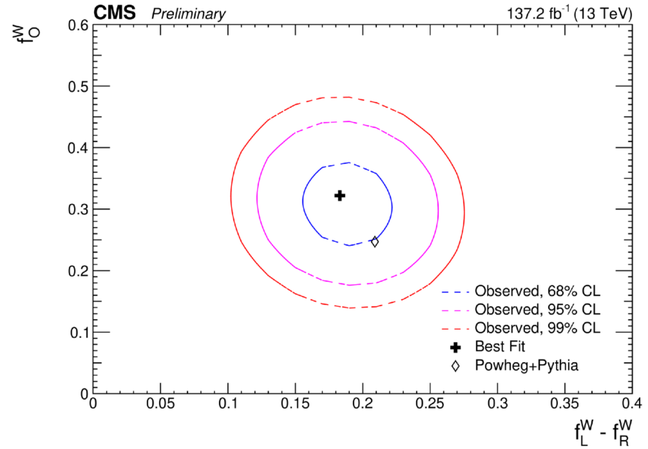
stringent limits on **anomalous triple gauge couplings** in terms of dim-6 EFT operators





Full Run-2, 137 fb^{-1}

CMS-PAS-SMP-20-014

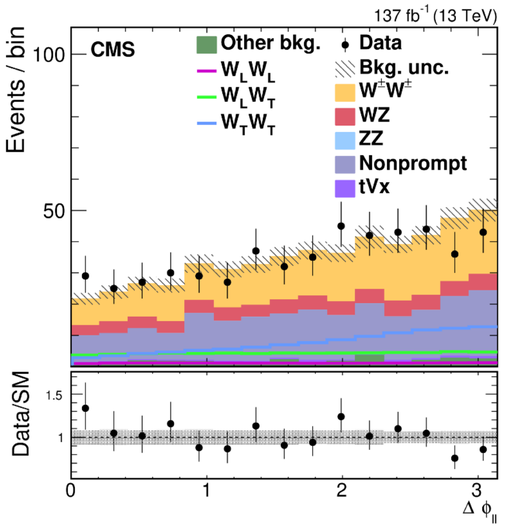


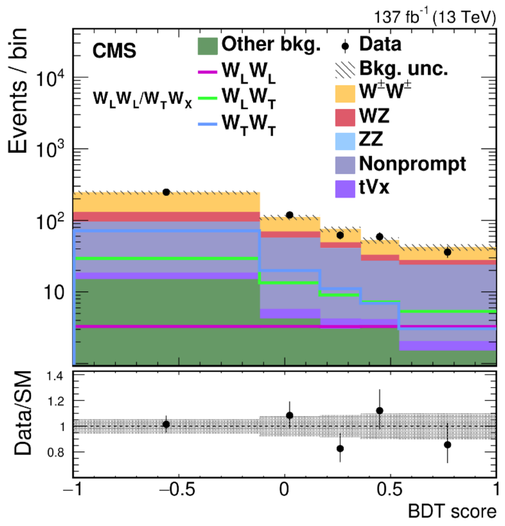
first observation of **longitudinally polarized W bosons** in WZ production

Vector Boson Scattering

Same-sign W pairs
with measurement of the polarisation

VBS signature: two jets with large rapidity separation and dijet mass





Process	$\sigma\,\mathcal{B}$ (fb)	Theoretical prediction (fb)
$W^{\pm}_{L}W^{\pm}_{L}$	$0.32^{+0.42}_{-0.40}$	0.44 ± 0.05
$W^{\pm}_{X}W^{\pm}_{T}$	$3.06^{+0.51}_{-0.48}$	3.13 ± 0.35
$W^{\pm}_{L}W^{\pm}_{X}$	$1.20^{+0.56}_{-0.53}$	1.63 ± 0.18
$W^{\pm}_{T}W^{\pm}_{T}$	$2.11^{+0.49}_{-0.47}$	1.94 ± 0.21

Exploiting event kinetics, extract polarisation components

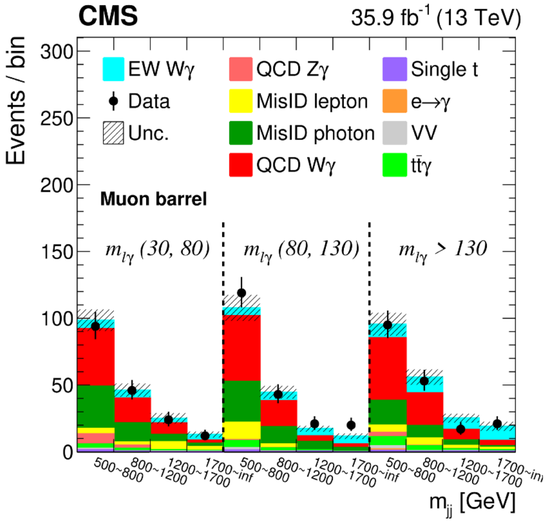
first hint the scattering of at least one W_L at the 2.3σ (3.1σ exp) level

CMS-SMP-20-006
PLB 812 (2020) 136018

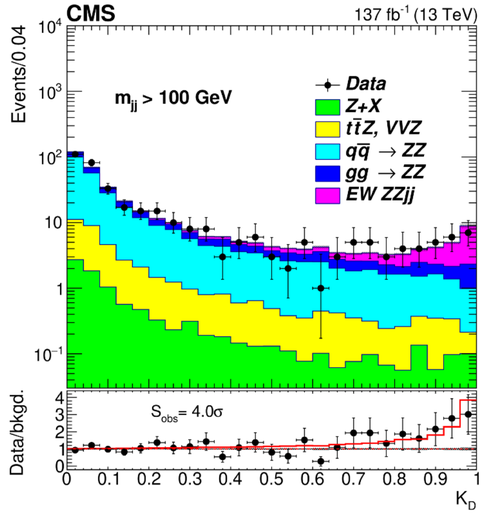
pp → Wγ jj

signal significance: 4.9σ (4.6σ exp)

CMS-SMP-19-008
PLB 811 (2020) 135988



Full Run-2, 137 fb⁻¹



pp → ZZ jj

signal significance: 4.0σ (3.5σ exp)

CMS-SMP-20-001
PLB 812 (2020) 135992

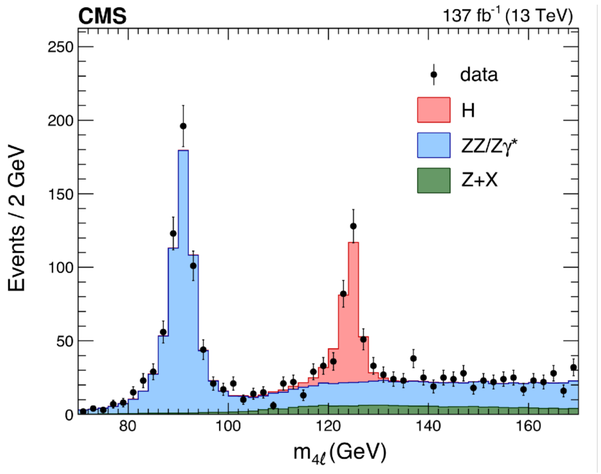
limits on **anomalous quartic gauge couplings** in terms of dim-8 EFT operators

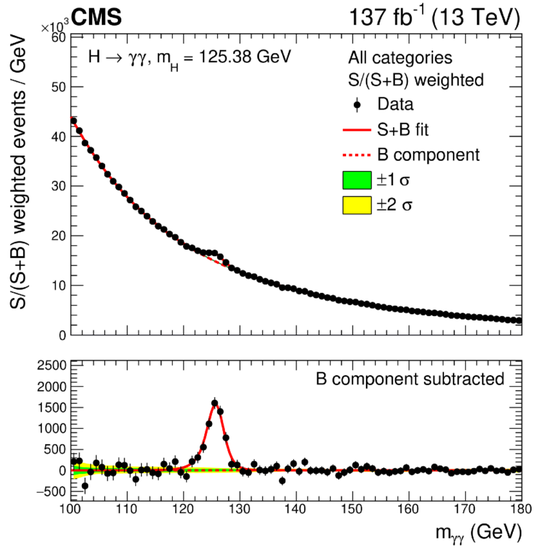
Fiducial cross section:

$$\sigma_{\mathrm{EW}}(\mathrm{pp} \to \mathrm{ZZjj} \to \ell\,\ell\,\ell'\,\ell'\,\mathrm{jj}) = 0.33^{+0.11}_{-0.10}\,(\mathrm{stat})^{+0.04}_{-0.03}\,(\mathrm{syst})\,\mathrm{fb}$$

SM: $0.28 \pm 0.02\,\mathrm{fb}$

Higgs Mass Measurements





H → ZZ → 4ℓ

$$m_{\mathrm{H}} = 125.26 \pm 0.21\,(\mathrm{total})\ \mathrm{GeV}$$

CMS-HIG-16-041
JHEP 11 (2017) 047

H → γγ

- using a refined calorimeter calibration

$$m_{\mathrm{H}} = 125.78 \pm 0.26\,(\mathrm{total})\ \mathrm{GeV}$$

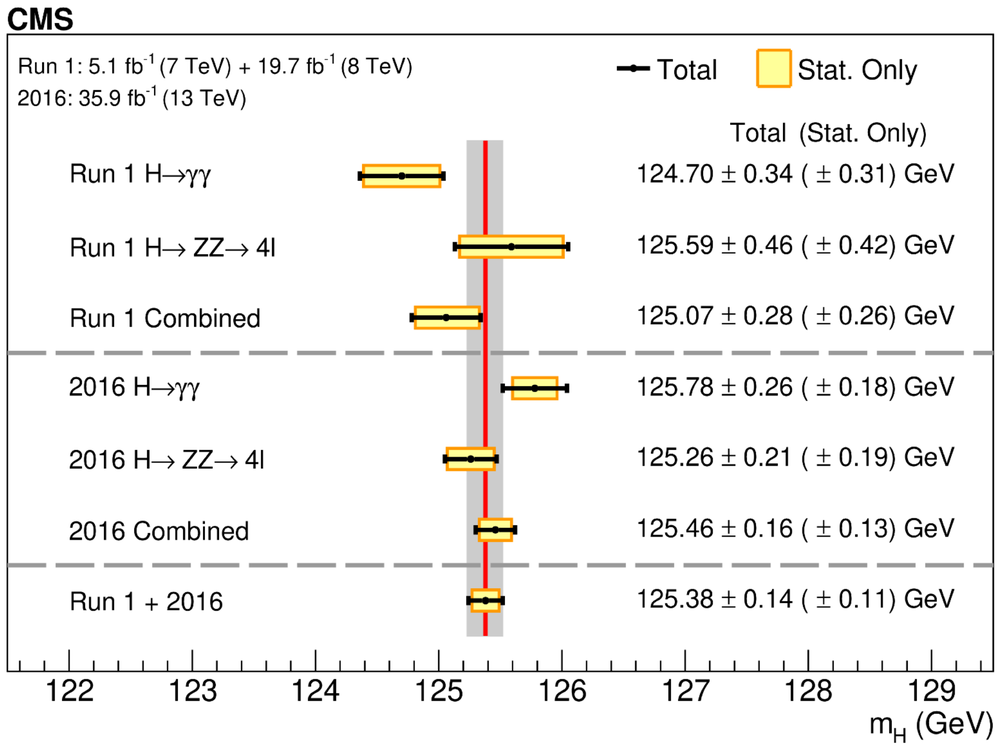
Run-2/2016 combination

$$m_{\mathrm{H}} = 125.46 \pm 0.16\,(\mathrm{total})\ \mathrm{GeV}$$

CMS-HIG-19-004
PLB 805 (2020) 135425

The Higgs boson mass measurement uncertainty is still dominated by statistics

Run-2 2016, 35.9 fb^{-1}

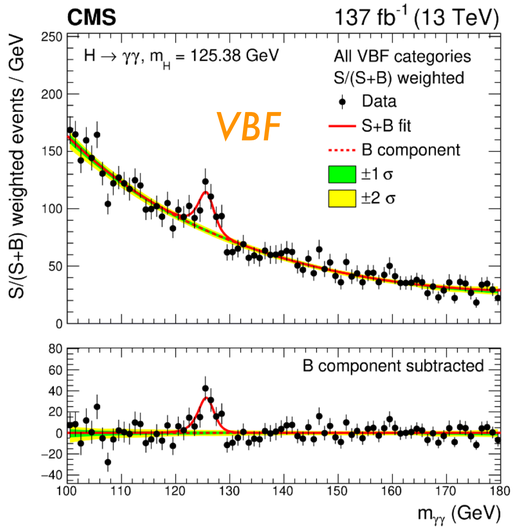


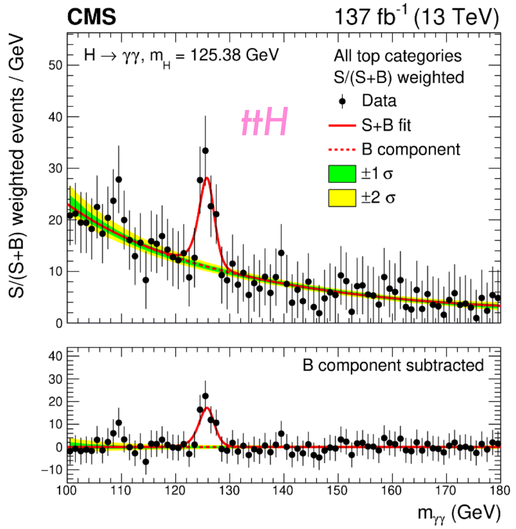
Combination with Run-1 result

$$m_{\mathrm{H}} = 125.38 \pm 0.14\,(\mathrm{total})\ \mathrm{GeV}$$

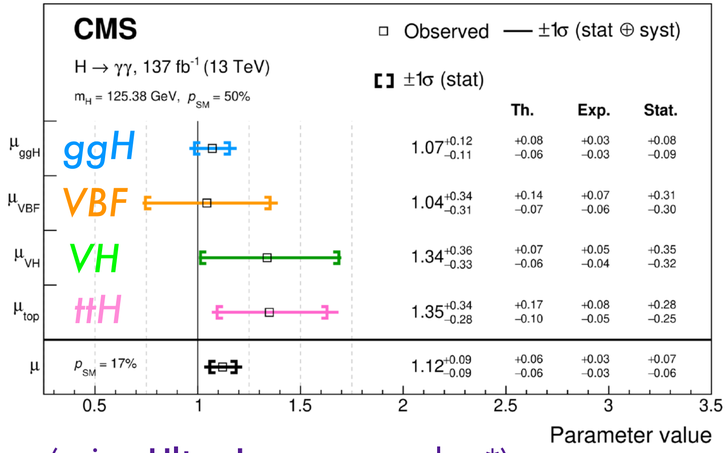
- currently the most precise measurement (1.1‰)
- central value consistently used in CMS analyses

H → γγ and STXS





Clear H → γγ signals in all four main production modes, including $pp \to t\bar{t}H$ (5.2σ)



(using **Ultra-Legacy** samples *)

$$\mu(\mathrm{pp} \to \mathrm{H} \to \gamma\gamma) = 1.12 \pm 0.09$$

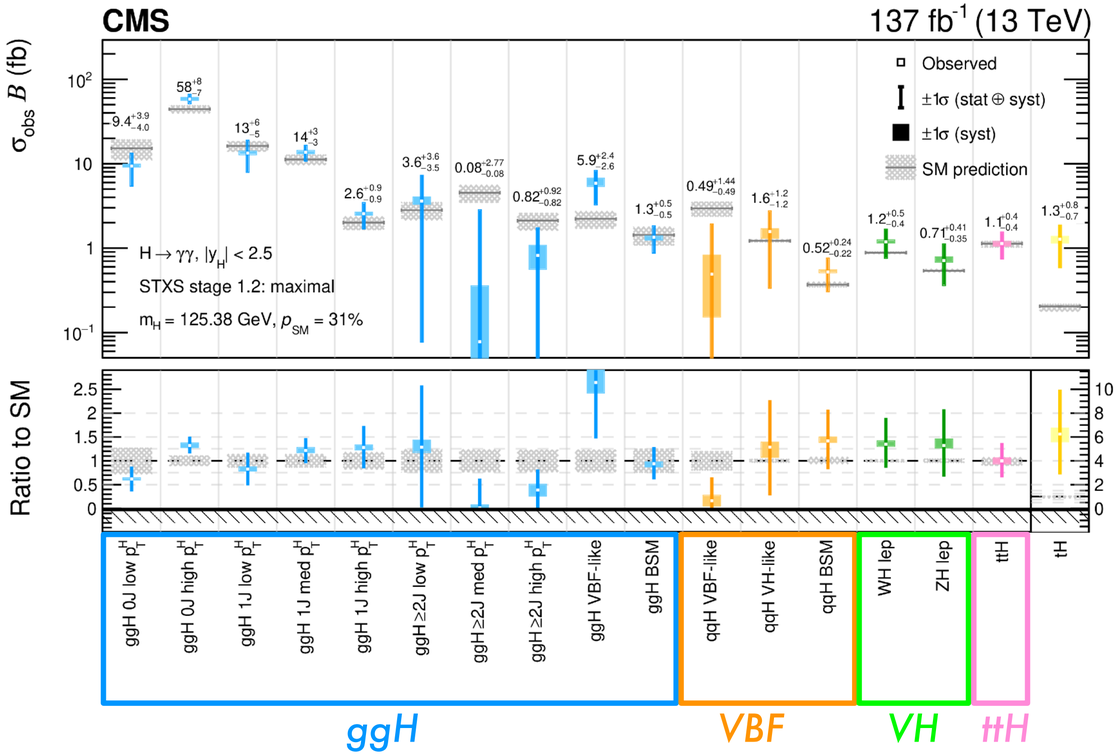
Also, strong evidence for $pp \to t\bar{t}H$ (4.7σ) in multi-lepton final states

CMS-HIG-19-015
Submitted to JHEP

Phys. Briefing

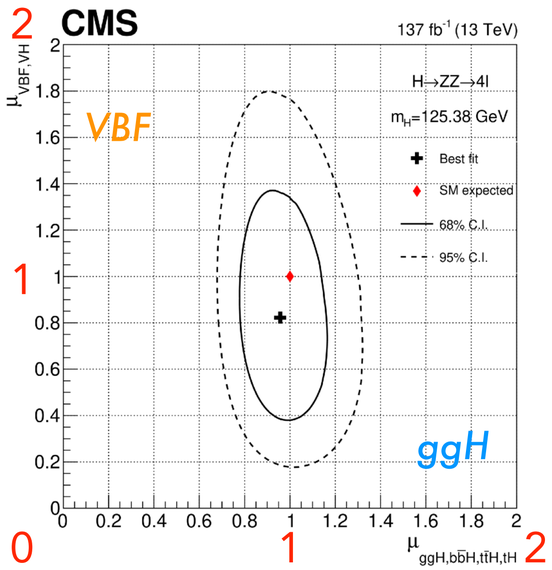
Full Run-2, 137 fb^{-1}

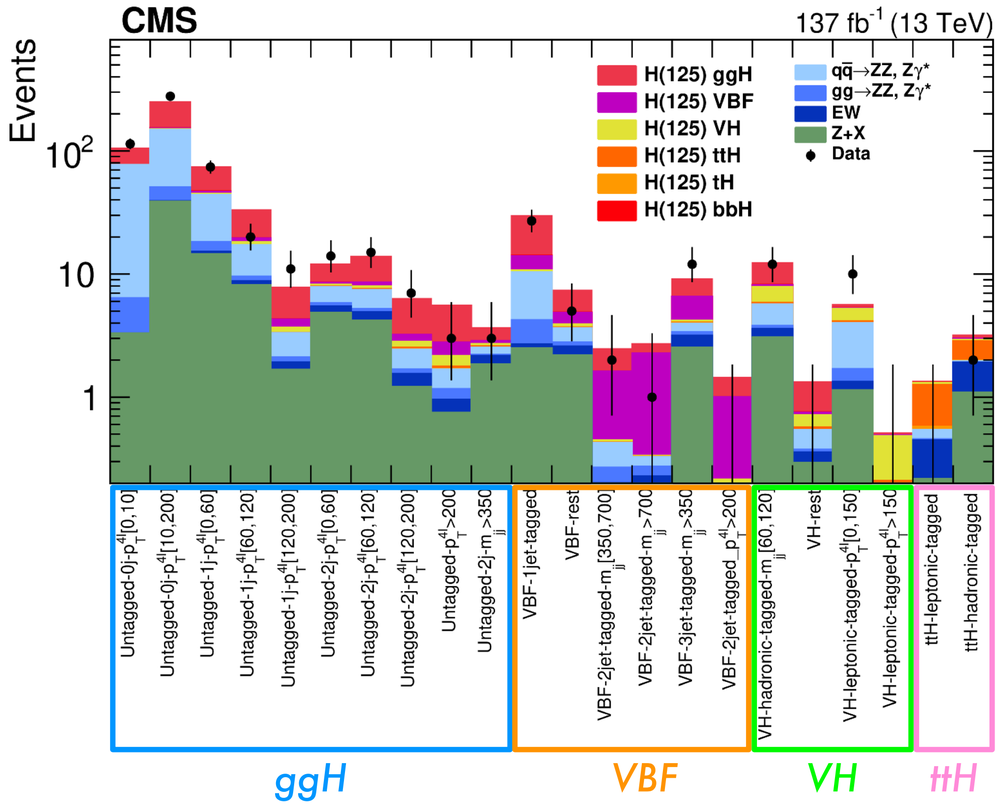
Measurements by production mode in various kinematic regions (STXS = Simplified Template Cross Sections)



(* already 40 analyses switched to Ultra Legacy re-reconstruction)

$H \to ZZ^* \to 4\ell$ and STXS





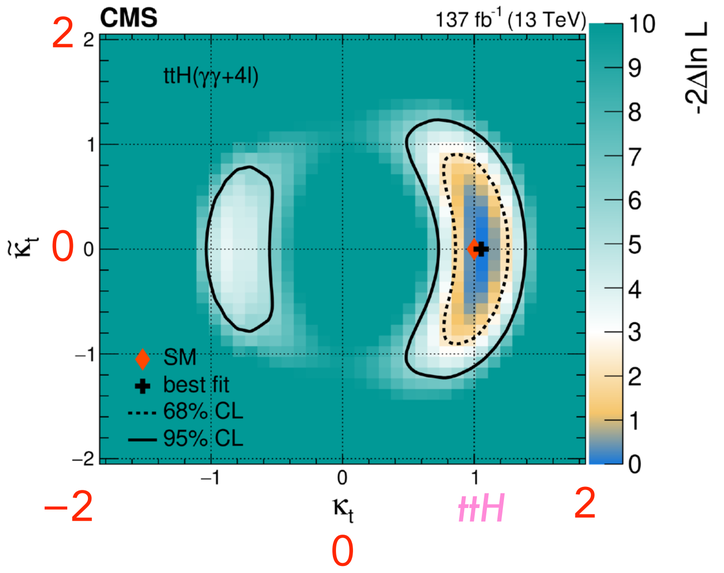
Full Run-2, 137 fb^{-1}

Also: comprehensive study of CP structure and anomalous couplings

CMS-HIG-19-009
Submitted to PRD

Phys. Briefing

Contraints on ttH anomalous CP coupling, combining $H \to 4\ell$ and $H \to \gamma\gamma$



$$\mu(4\ell) = 0.94 \pm 0.07\,(\text{stat})^{+0.09}_{-0.08}\,(\text{syst})$$

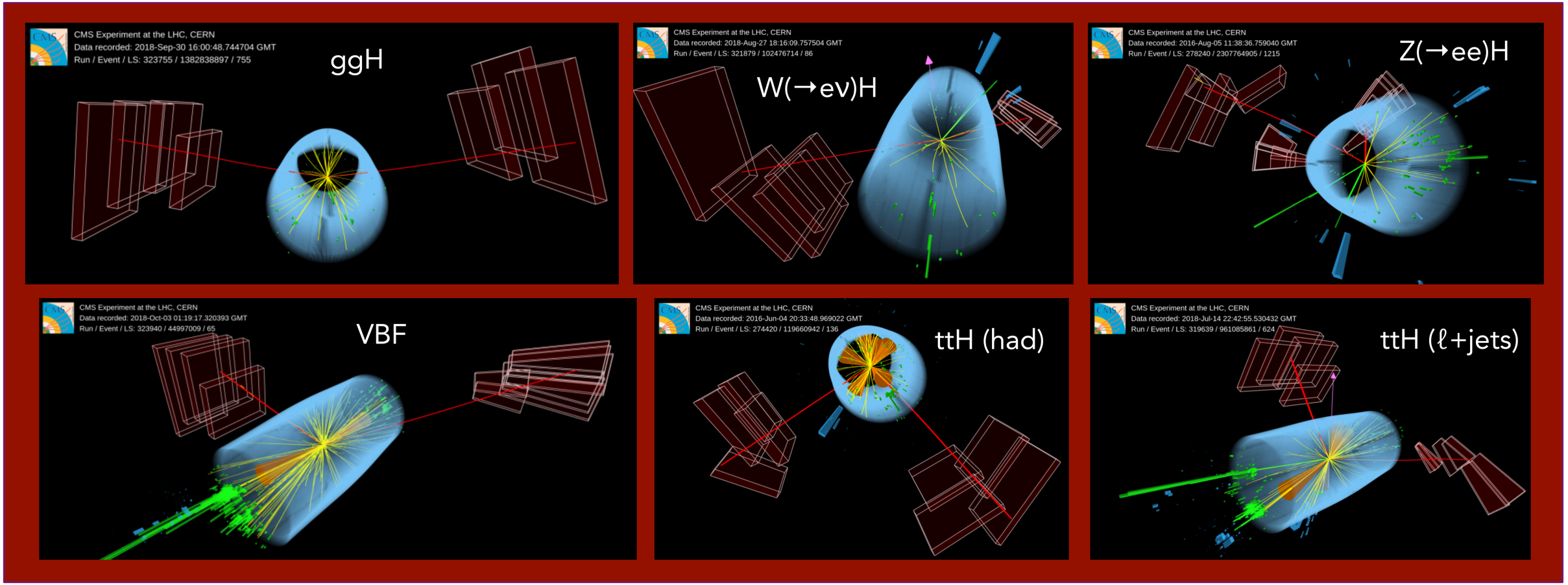
$$\sigma_{\text{fid}}(4\ell) = 2.84^{+0.23}_{-0.22}\,(\text{stat})^{+0.26}_{-0.21}\,(\text{syst})\ \text{fb}$$

SM: 2.84 ± 0.15 fb

CMS-HIG-19-001
Accepted by EPJC

First Evidence for H → μμ

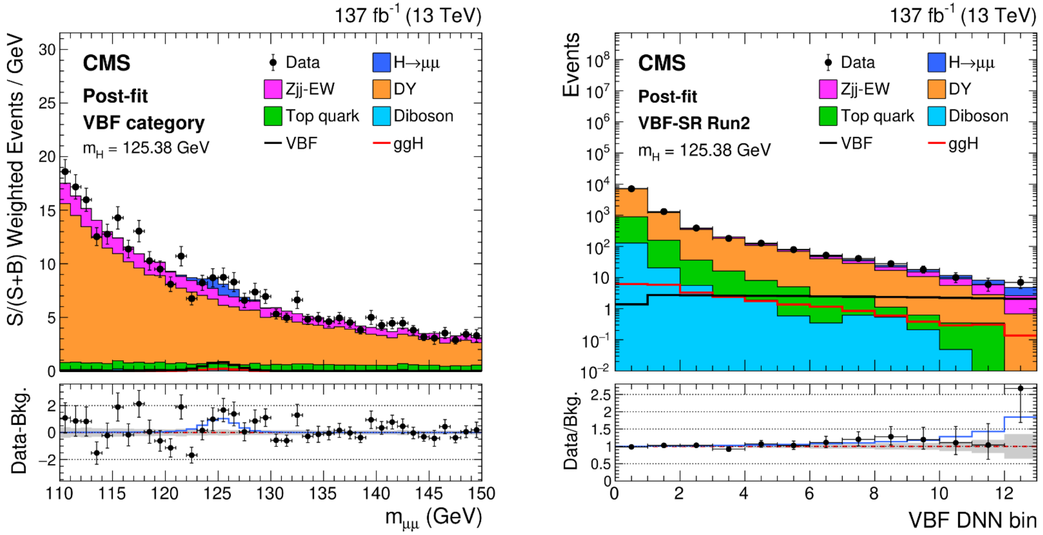
Exclusive categories: ggH, VBF, VH and ttH



First Evidence for H → μμ

Analysis in VBF category

- makes use of advanced machine learning techniques
- provides sensitivity similar to that in ggH



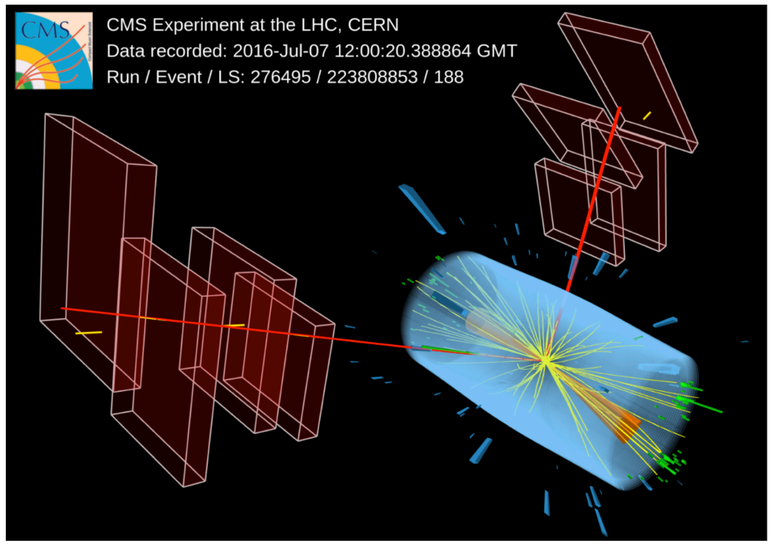
$$\mu(\mu\mu) = 1.19^{+0.41}_{-0.39}\,(\text{stat})^{+0.17}_{-0.16}\,(\text{syst})$$

Obs. (exp.) significance: 3.0 (2.5) σ

CMS-HIG-19-006
JHEP 01 (2021) 148

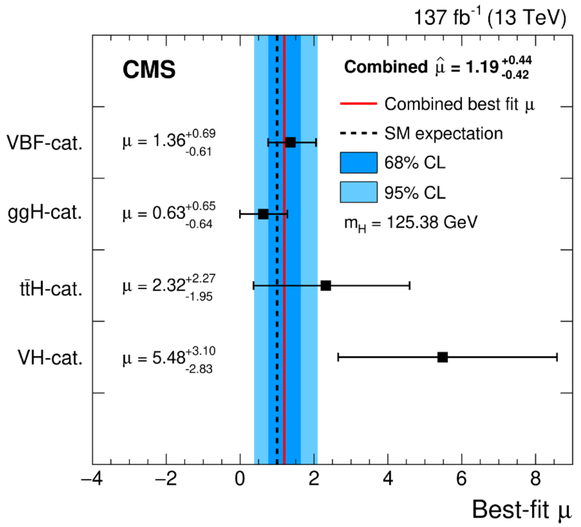
Phys. Briefing

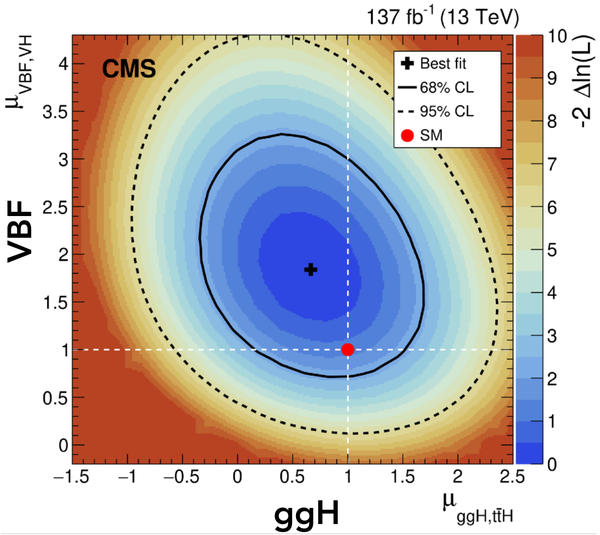
Combining with Run-1 (7 and 8 TeV) improves significance by 1%



Full Run-2, 137 fb⁻¹

Drell-Yan background considerably reduced by VBF topology requirement (two forward jets)



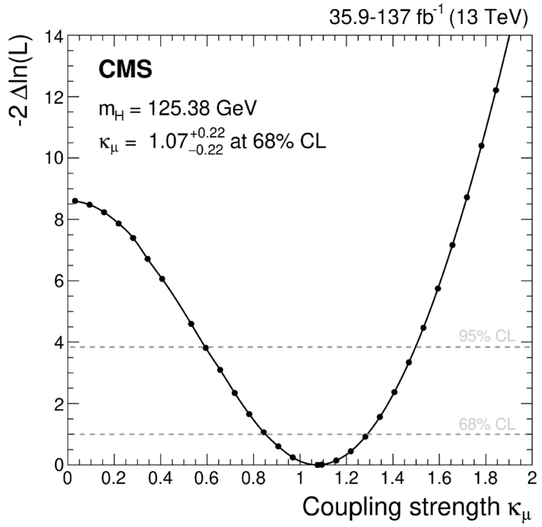


using $m_H = 125.38$ GeV (best CMS result)

Summary of Higgs Couplings

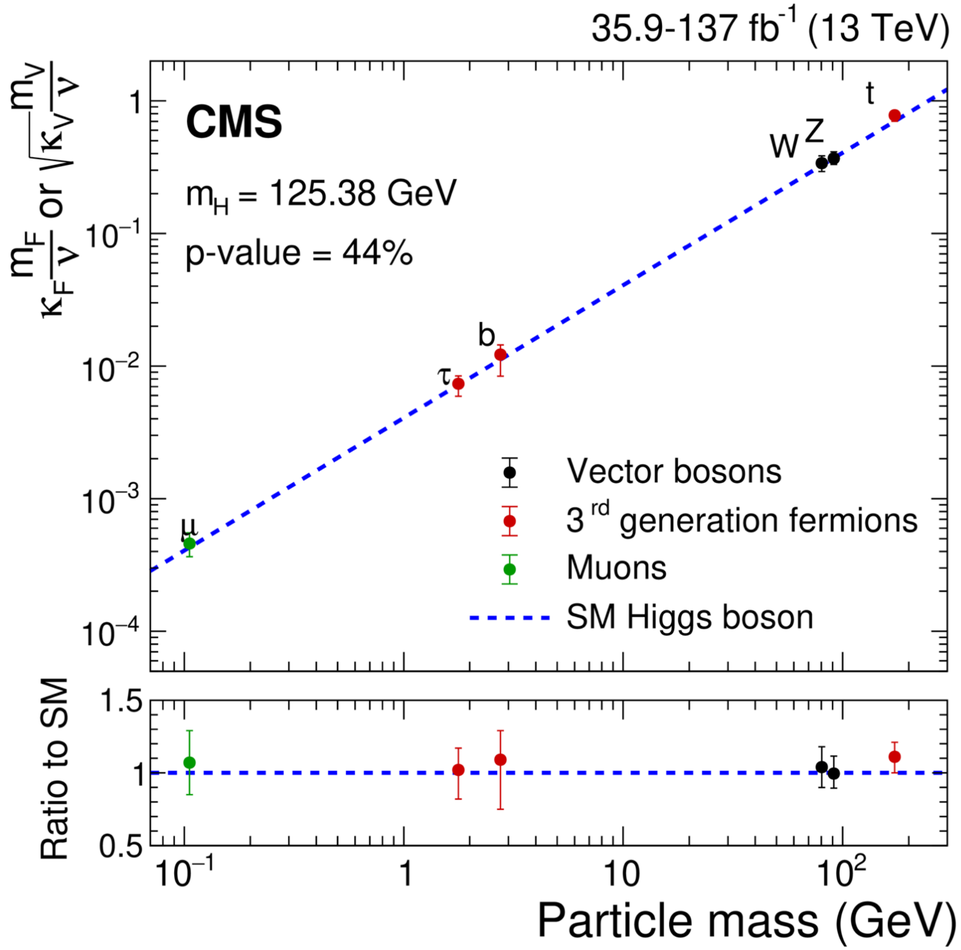
In the **kappa framework** , fit for 6 coupling strength modifiers (κ) for $m_{\mathrm{H}} = 125.38\,\mathrm{GeV}$

$$\kappa_\mu = 1.07 \pm 0.22\,(\mathrm{at}\ 68\%\mathrm{CL})$$



CMS-HIG-19-006
JHEP 01 (2021) 148

for the first time, meaningful 68% and 95% confidence intervals for a Higgs boson coupling to a second generation fermion

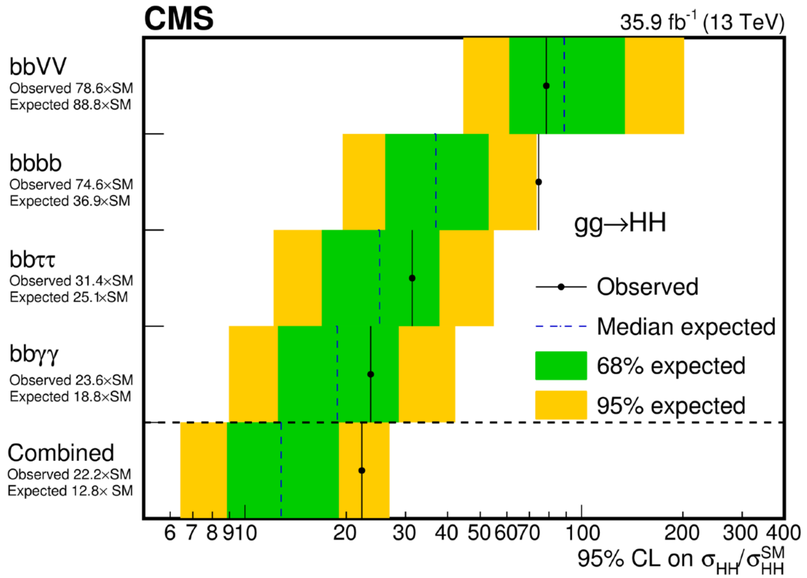


CMS *p*-value for SM hypothesis (all κ=1): **44%**

Search for Double Higgs Production

Run-2 2016, 35.9 fb^{-1}

CMS-HIG-17-030
PRL 122 (2019) 121803

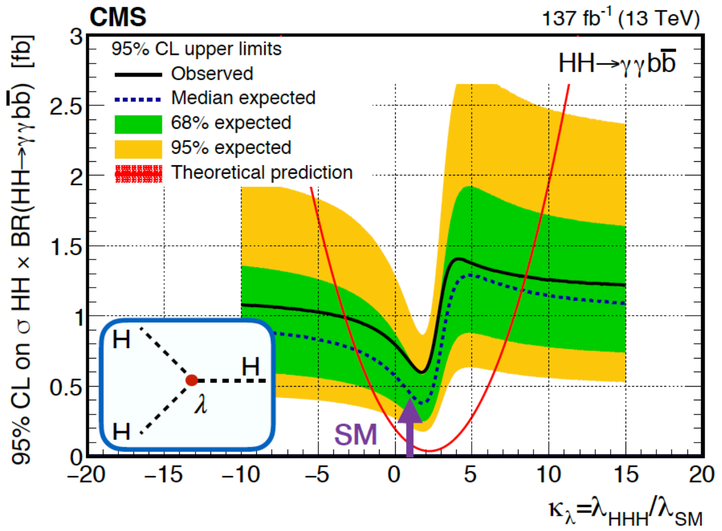


Combination of HH searches
$\sigma/\sigma_{SM} < 22$ (13) at 95% CL

Full Run-2, 137 fb^{-1}

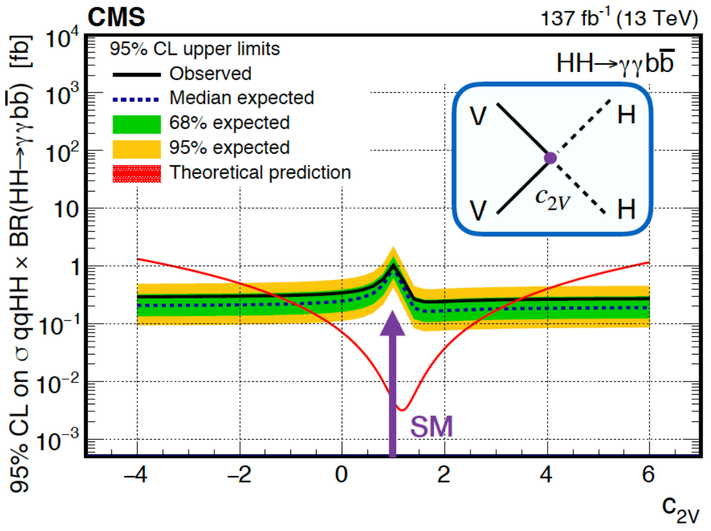
CMS-HIG-19-018
JHEP 03 (2021) 257

Phys. Briefing



Driven by ggF categories

Inclusive $\mathrm{HH} \to \gamma\gamma\mathrm{b\bar{b}}$
$\sigma/\sigma_{SM} < 7.7$ (5.2) at 95% CL



Driven by VBF categories

VBF $\mathrm{HH} \to \gamma\gamma\mathrm{b\bar{b}}$
$\sigma/\sigma_{SM} < 225$ (208) at 95% CL

Constraints on anomalous
HHH (κ_λ) and VVHH (c_{2V}) couplings

In SM: $\lambda_{\mathrm{HHH}} = \lambda = m_{\mathrm{H}}^2/2v^2$

Top-Quark Mass Measurements

In the SM, the value of the *Instability Scale* Λ (> 10^9 GeV) depends on $\alpha_S(m_Z)$ and the **top-quark mass** $m(t)$

From $t\bar{t}$ events

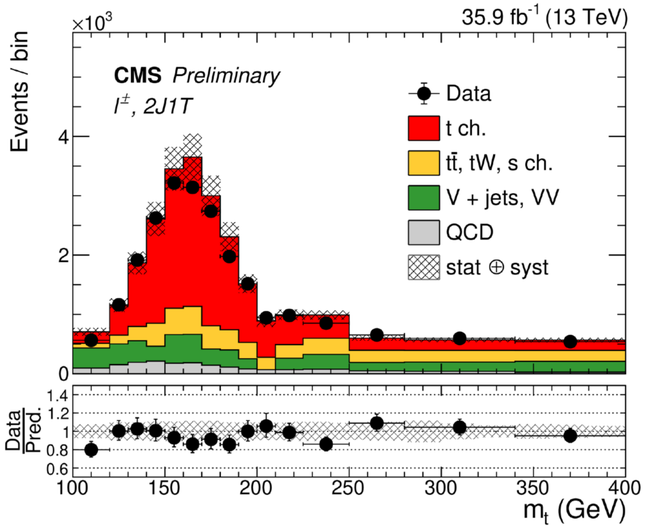
- **Run-1 legacy**

  $m(t) = 172.44 \pm 0.13 \pm 0.47$ GeV

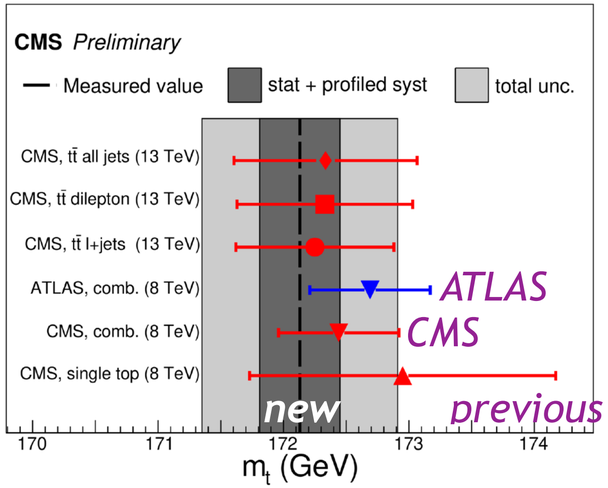
- **Run-2 lepton+jets**

  $m(t) = 172.25 \pm 0.08 \pm 0.62$ GeV

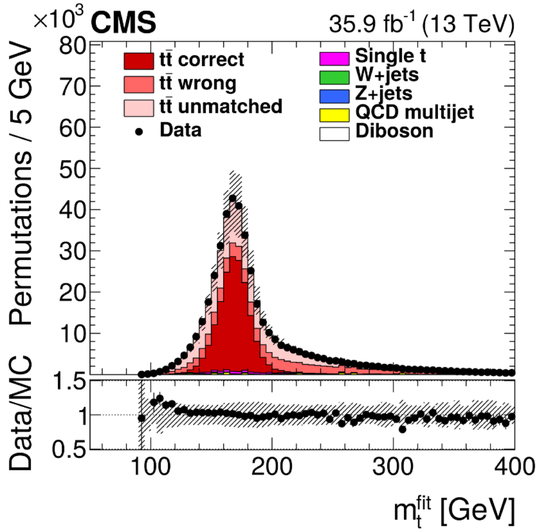
Run-2 2016, 35.9 fb^{-1}



CMS-PAS-TOP-19-009



CMS-TOP-17-017
EPJC 78 (2018) 891



From single top events

Different phase space, different kinematics, and separate measurements of top and anti-top:

- $m(t) = 172.44 \pm 0.77$ GeV
- $m(\bar{t})/m(t) = 0.995 \pm 0.006$
- $m(\bar{t}) - m(t) = 0.83^{+0.77}_{-1.01}$ GeV

Alternative methods

- M_{T2}, Dilepton $M_{\ell b}$, kinematic endpoints, b-hadron lifetime, ℓ+SecVtx, ℓ+J/ψ, etc.
- less precise but different systematic uncertainties
- in agreement with main measurement

Running of the Top-Quark Mass

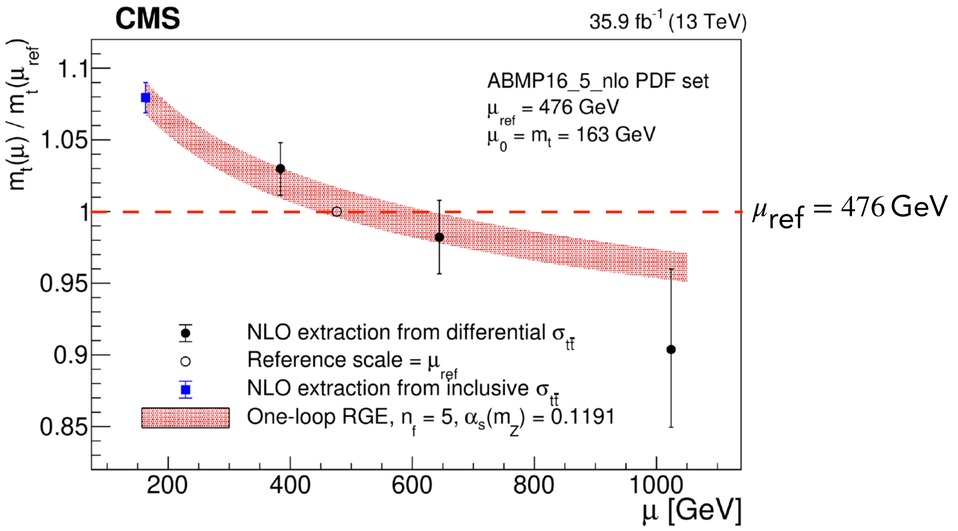
"Pole" mass from multi-differential cross section measurements

- in $e^{\pm}\mu^{\mp}$ final state
- as functions of mass and rapidity of the $t\bar{t}$ system, and jet multiplicity
- unfolded at parton level
- compared with NLO predictions in $\overline{\text{MS}}$ scheme

$$m(\text{t}) = 170.83 \pm 0.72\,\text{GeV}$$

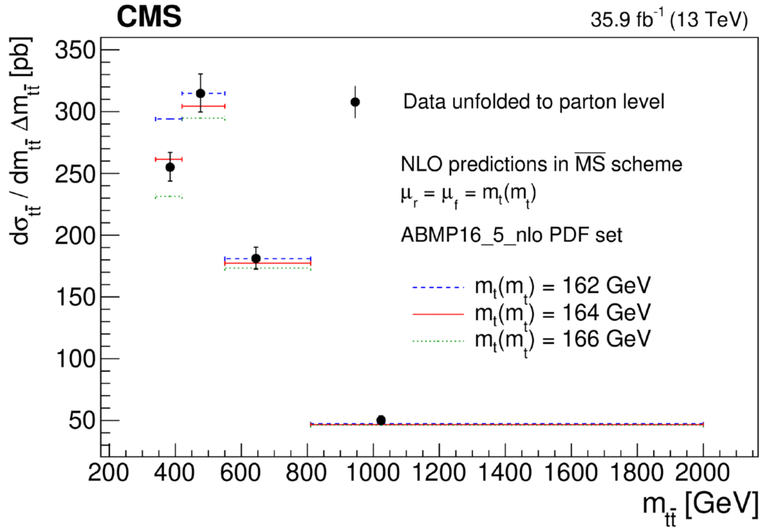
CMS-TOP-18-004
EPJC 80 (2020) 658

Run-2 2016, 35.9 fb^{-1}



Evolution of the top quark mass from the differential cross section as a function of $m_{t\bar{t}}$

$d\sigma_{t\bar{t}}/dm_{t\bar{t}}$



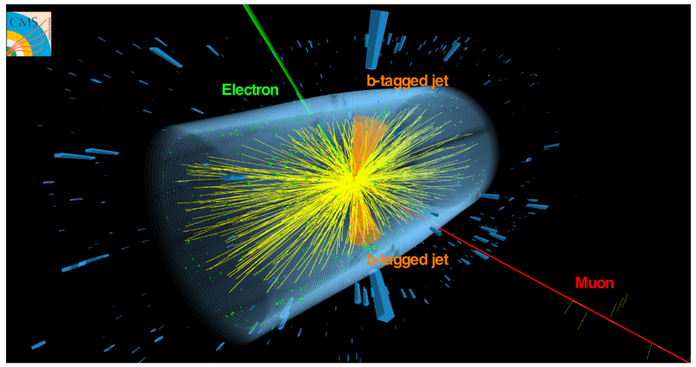
CMS-TOP-19-007
PLB 803 (2020) 135263

uncertainty evolved from inclusive measurement at scale $\mu_0 = 163\,\text{GeV}$

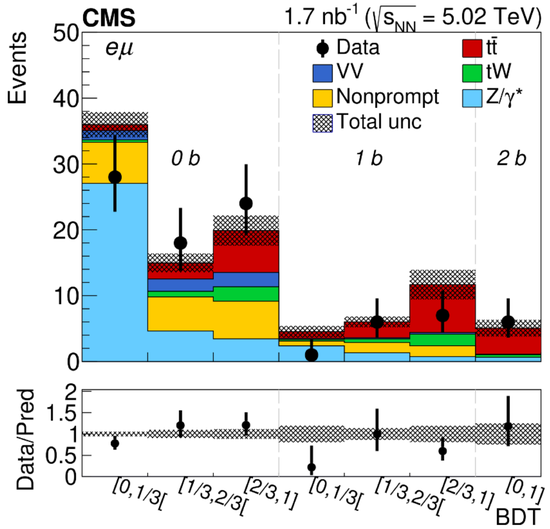
Top-quark running mass probed up a scale of order 1 TeV

- compared to RGE prediction at one-loop precision ($n_f = 5$)
- scale dependance found consistent with predictions at the 1.1σ level
- no-running hypothesis excluded at the 95% CL

Heavy Quark Production in PbPb Collisions



Run-2, $\sqrt{s_{NN}}$ = 5.02 TeV, PbPb 1.7 nb^{-1} + pp 320 pb^{-1}



Evidence for $t\bar{t}$ production

- in the eμ channel
- 4.0σ obs. (6.0σ exp.)
- following a first observation in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

CMS-HIN-19-001
PRL 125 (2020) 222001

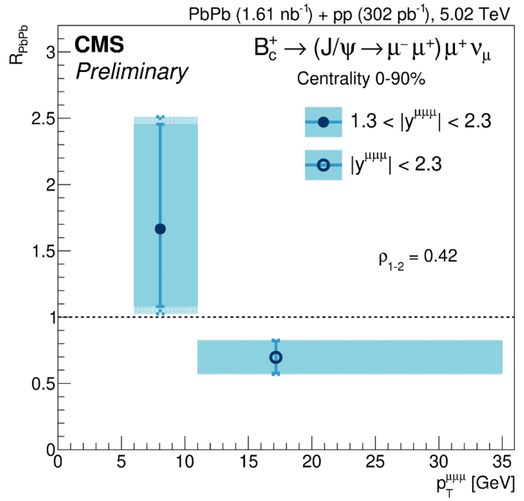
Phys. Briefing

Top quarks are thought to decay before QGP formation

- probes for nPDF at high-x
- tools to study parton energy loss in the QGP

Observation of B_c meson production

- in the decay channel $B_c \rightarrow J/\psi(\rightarrow\mu\mu)\mu\nu$ ($\gg 5\sigma$)
- bridge between charm and charmonium



CMS-PAS-HIN-20-004

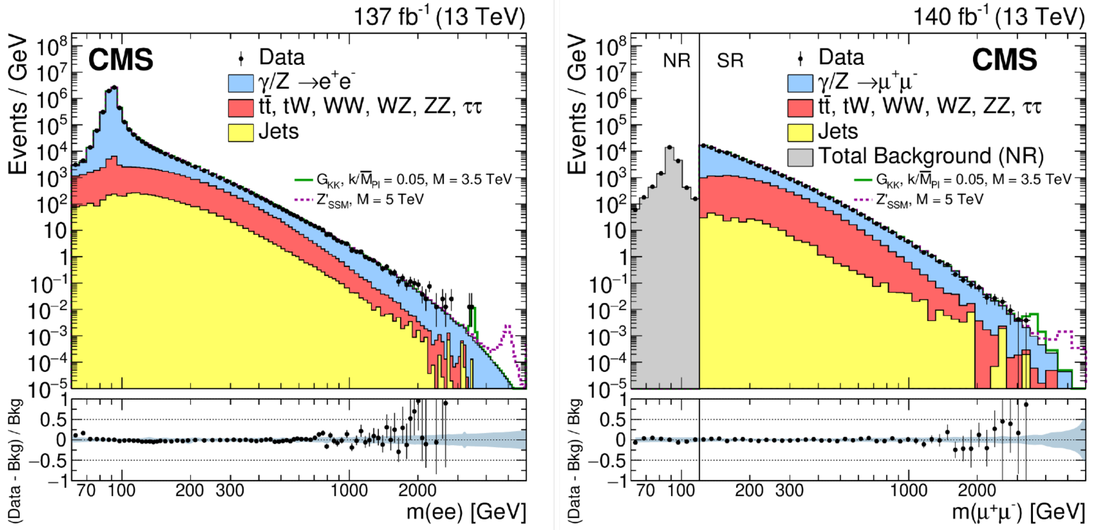
- hint of soften p_T spectrum
- rules out some (extreme) models of charm recombination

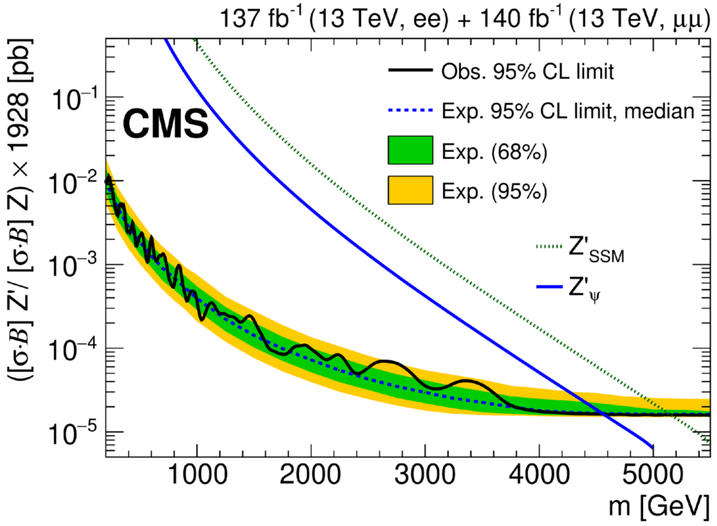
will help disentangle the enhancement and suppression mechanisms at play in the evolution of heavy quarks through the QGP

Search for Heavy Resonances

Dilepton resonances

Full Run-2, ≥137 fb^{-1}





[CMS-EXO-19-019](#)
Submitted to JHEP

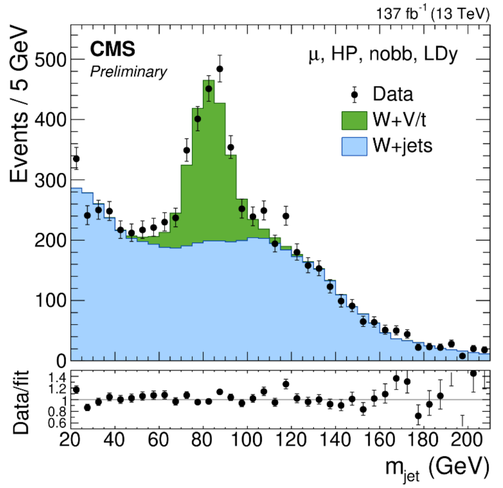
[Phys. Briefing](#)

Limits on cross section × BF translate into limits on resonance masses

depending on models new W′ or Z′ resonances with masses up to > 4 TeV are excluded

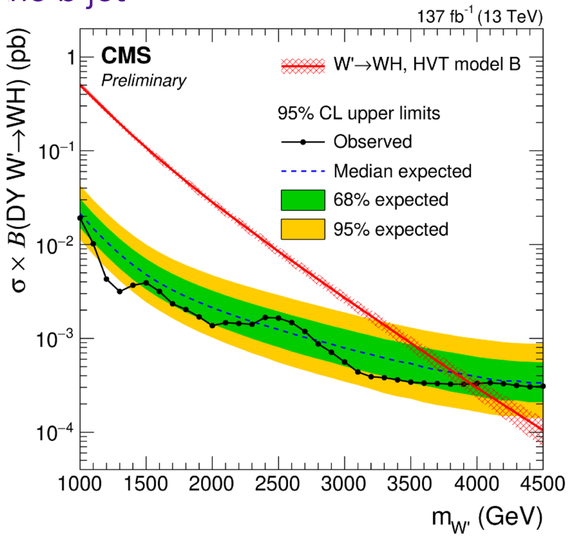
Diboson resonances

[CMS-PAS-B2G-19-002](#)



WW, WZ, WH in lepton + merged jet final state

muon channel
$|\Delta y|<1$
no b jet

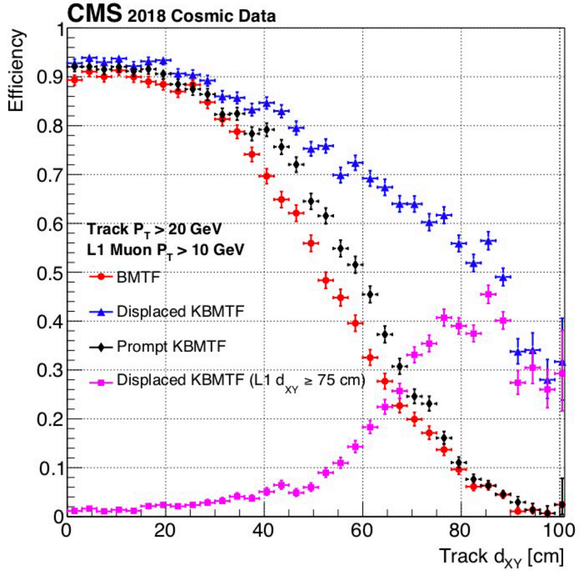


Focus of Run-3: searches for long-lived particles (LLP)

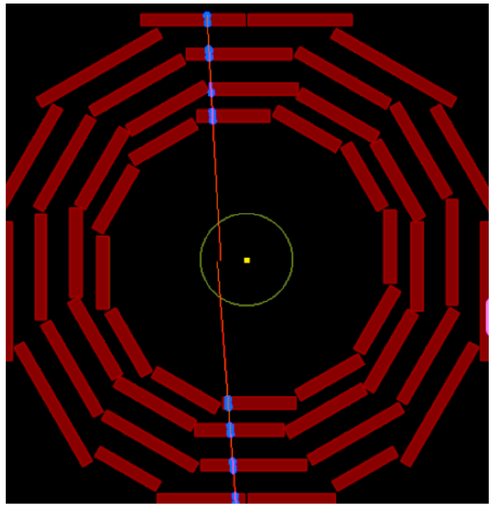
Preparation for Run-3

L1-Muon trigger

- Kalman track finding that provides better efficiency for displaced muons (without vertex constraint)



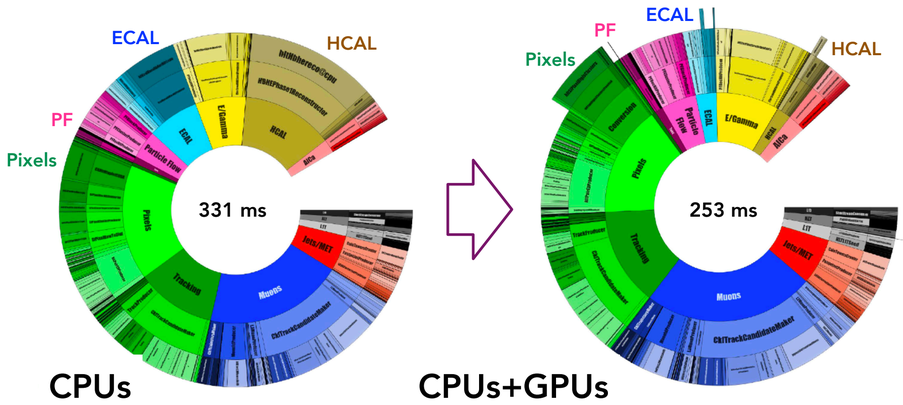
tested in parallel in 2018 and commissioned with cosmic rays



Computing and Offline software

- increased use of opportunistic computing (HPC: 10-15%)
- 10% faster full simulation
- improved fast simulation
- development of event lighter data formats

Heterogeneous online reconstruction



measured on PU 50 events

GPUs in High-Level Trigger (HLT)

A significant (and growing) fraction of the online reconstruction code is off-loaded from CPUs to GPUs

- HCAL and ECAL local reconstruction and calibration
- pixel tracking and electron seeding
- some particle flow and jet algorithms

A significant improvement in speed (>20%) already with present 30% of Run-3 workflow

CMS Phase-II Upgrades

Tracker
- all silicon (strips and pixels)
- higher granularity (>2B channels)
- less material
- coverage extended to $|\eta| = 4$

Barrel Calorimeters
- crystal granularity readout at 40 MHz
- precise timing for e/γ > 30 GeV
- ECAL operation at low temperature (10°)
- upgraded laser monitoring system

A MIP Timing Detector (MTD)
- precision timing on single charged tracks (30 to 40 ps resolution)
- Barrel (BTL): LYSO crystals + SiPMs
- Endcaps (ETL): Low Gain Avalanche Diodes

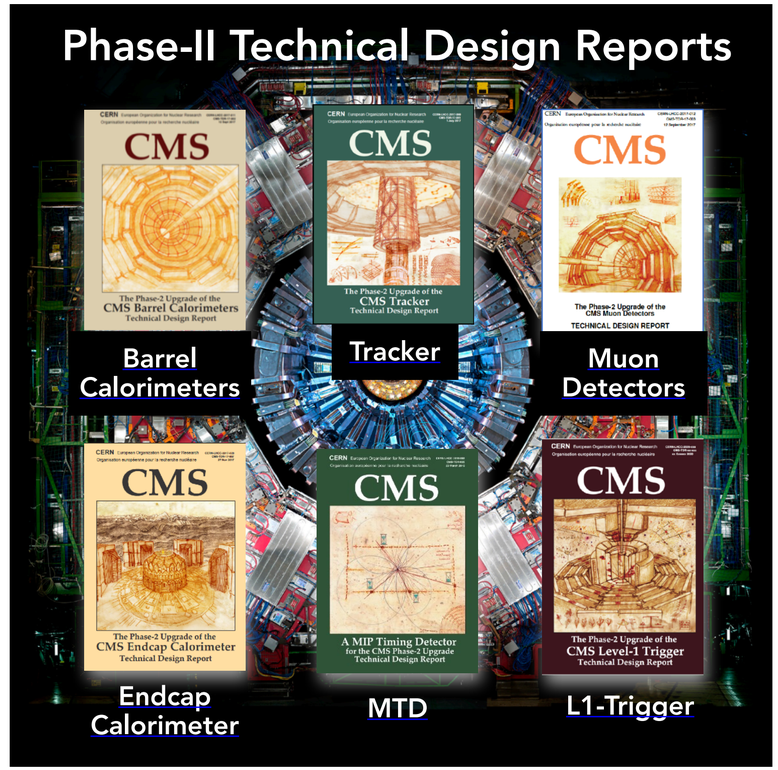
Endcap Calorimeter (HGCAL)
- silicon pixels (EM) and scintillators + SiPMs (HAD)
- 3D shower reconstruction with precise timing

Muon Detectors
- DTs & CSCs: new FE/BE readout electronics
- RPCs: new electronics
- new GEM/iRPC chambers
- extended muon coverage to $|\eta| = 3$

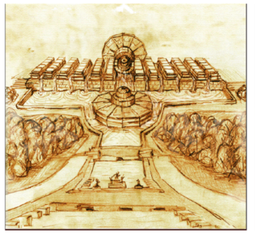
L1-Trigger
- track trigger at L1 (40 MHz)
- latency up to 12.5 μs
- triggers on displaced muons and long-lived particles

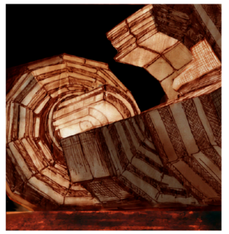
DAQ/HLT
- HLT output at 7.5 kHz

Beam Radiation Instrumentation and Luminosity (BRIL)
- BCM/PLT refit
- new T2 tracker



Yet to come (June 2021):


DAQ/HLT

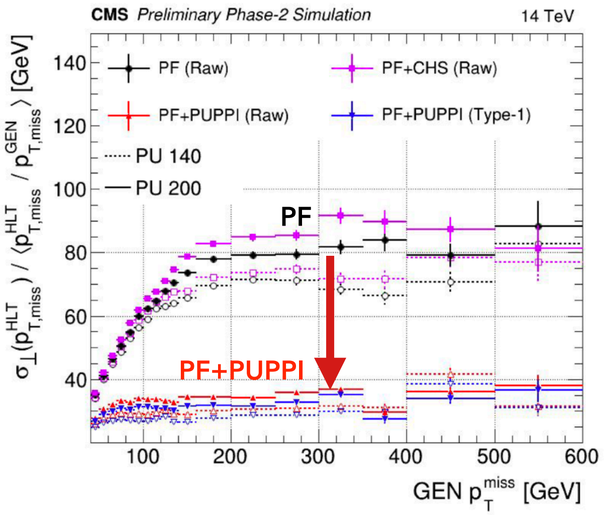

BRIL

See talk by **Santiago Folgueras** on Friday

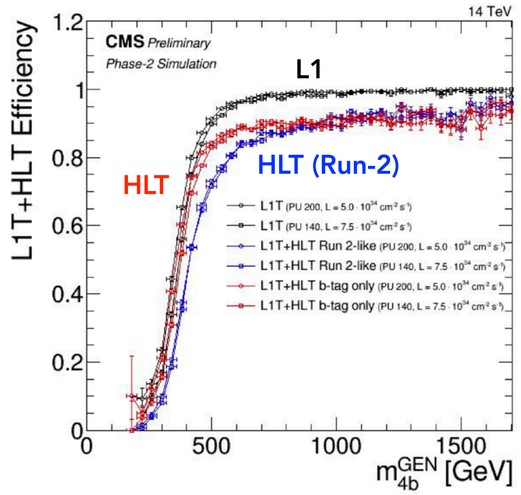
Highlights of Coming TDRs

Phase-II HLT (not aiming at demonstrating final performance)

- Physics performance already matching expectations with thresholds similar to that of Run-2
- Timing-wise, **only** a factor ~2 still to be gained for Run-4



Response-corrected MET resolution
The PUPPI algorithm (red) mitigates PU effectively.



$HH \to b\bar{b}b\bar{b}$ **trigger efficiency**
L1T (black), L1T+HLT with Run-2 algorithm (blue), L1T+HLT with lower p_T and H_T thresholds and DeepCSV b-jet tagging (red) for same rate (50Hz)

Phase-II Luminosity

- **Offline** bunch-by-bunch luminosity with **1%** precision
- **Online** & orbit integrated luminosity with **<2%** precision
  - even outside CMS data taking

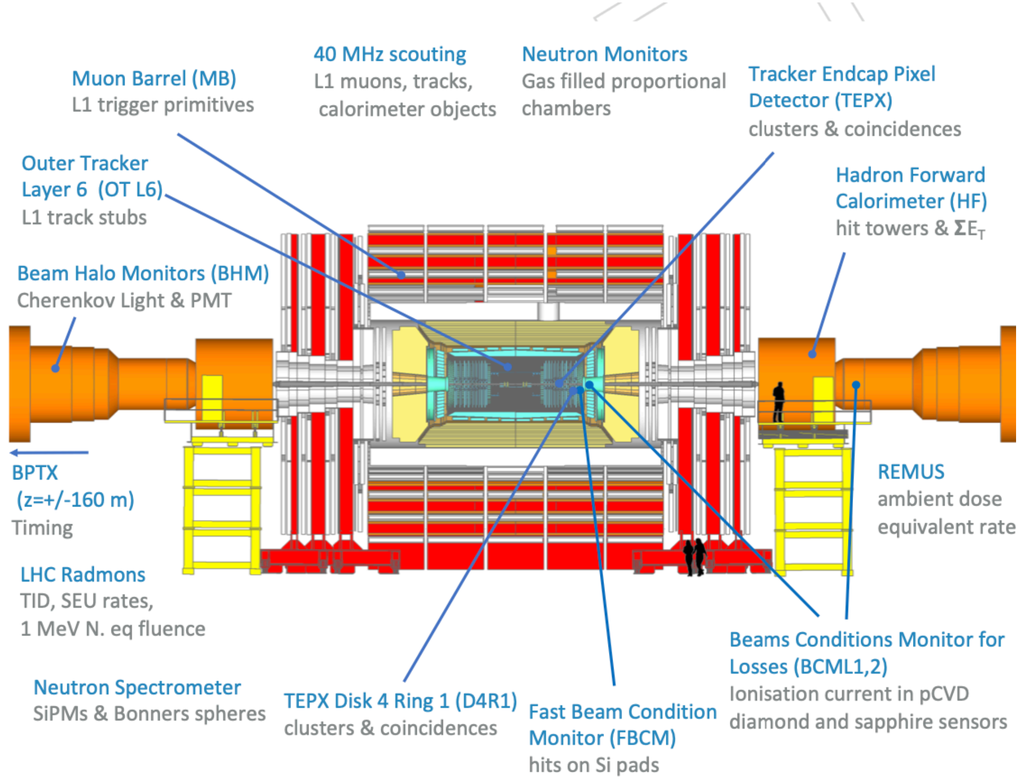


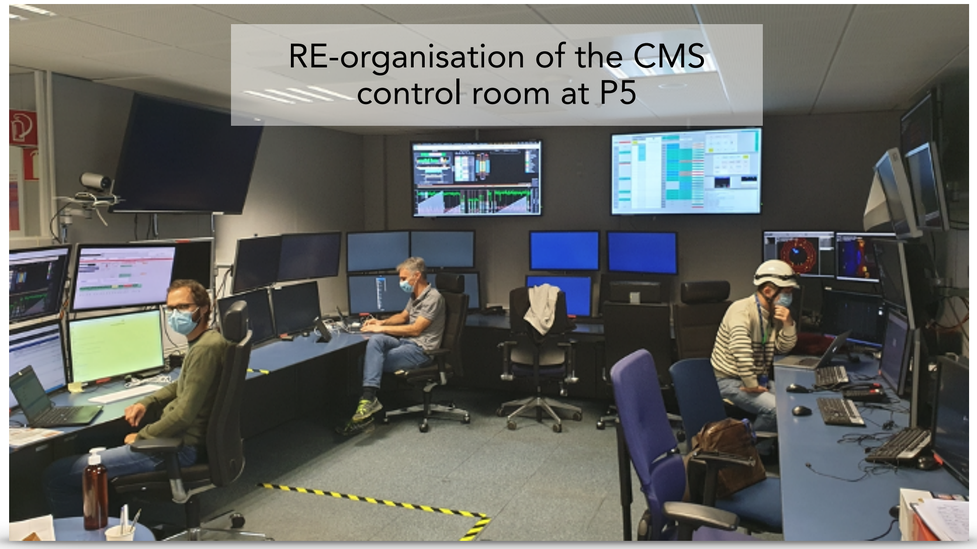
Figure 1.5: Subsystems to be used for the CMS BRIL Phase-2 measurements for HL-LHC.

Summary

Despite the pandemic, the CMS LS2 activities are progressing well

- upgrade of the Hadron Calorimeter *completed*
- first Phase-II muon detector *installed*
- new beam-pipe for Phase-II *installed*
- pixel detector *fully refurbished*

CMS is looking forward to the **Pilot Beam Test** and the **start of the Run-3**


RE-organisation of the CMS control room at P5

Work at Point 5

- with 75% of normal efficiency despite anti-COVID precautions and quarantines
- mostly performed by teams of long-term locally resident users, re-organised to minimise inter-group interactions

Phase-II Upgrades

- excellent progress in all projects, but tight schedule
- delays of 3 months due to lockdown and up to 8 months due to partial closure of facilities, delays in procurement, travel restrictions, etc.
- two upcoming TDRs: **DAQ/HLT** and **BRIL**

CMS continues to deliver physics results at a steady pace

- no indication of loss of productivity
- however, signs of stress due to massive telework, lack of in-person meetings and absence of social interaction, especially among our younger collaborators

We are continuously monitoring the **impact of the pandemic** on our activities and our collaborators. We are mindful of the **long-term effects** that the pandemic may have.

CMS Collaborators at LHCP 2021

Plenary Session Speakers

- Experimental Results on Exotic Searches
  Halil Saka (Univ. of Cyprus)
- Dark matter: overview of direct/indirect searches
  Deborah Pinna (Univ. of Wisconsin)
- Experimental results on tt+X
  Joshuha Thomas-Wilsker (IHEP)
- Experimental results on Higgs measurements
  Pierluigi Bortignon (Univ. di Padova e INFN)
- EWK precision measurements
  Ilya Gorbunov (JINR)
- VBS and VBF measurements
  Roberto Covarelli (Univ. di Torino e INFN)
- Heavy Flavours - rare decays
  Alessio Boletti (LIP)
- CMS upgrades
  Santiago Folgueras (Univ. de Oviedo)
- Outreach and diversity
  Brajesh Choudhary (Univ. of Delhi)

Parallel Session Speakers

- **Barbara Alvarez Gonzalez** (Univ. de Oviedo)
- **Juan Gonzalez** (Univ. de Oviedo)
- **Nils Faltermann** (Inst. für Exp. Kernphysik)
- **Mintu Kumar** (Tata Institute-A)
- **Rajat Gupta** (Panjab Univ.)
- **Markus Seidel** (Univ. of Maryland)
- **Salim Cerci** (Istanbul University)
- **Matteo Presilla** (Univ. di Padova e INFN)
- **Alicia Calderon Tazon** (Univ. de Cantabria)
- **Christophe Royon** (The Univ. of Kansas)
- **Riccardo Salvatico** (The Univ. of Kansas)
- **Guillaume Falmagne** (LLR, IN2P3-CNRS)
- **Georgios Krintiras** (The Univ. of Kansas)
- **Christina Reissel** (ETH Zürich)
- **Kajari Mazumdar** (Tata Institute-B)
- **Roberto Seidita** (Univ. di Firenze e INFN)
- **Alberto Orso Maria Iorio** (INFN di Napoli)
- **Antonios Agapitos** (Peking Univ.)
- **Christian Herwig** (Fermi National Accelerator Lab.)
- **Daniel Spitzbart** (Boston Univ.)
- **Matthias Komm** (CERN)
- **Aran Garcia-Bellido** (Univ. of Rochester)
- **Claudia Wulz** (HEPHY)
- **Laurent Forthomme** (Univ. of Helsinki)
- **Mia Tosi** (Univ. di Padova e INFN)
- **Swagata Mukherjee** (RWTH, III. Physik. Inst. A)
- **Nadja Strobbe** (Univ. of Minnesota)
- **Samuel Louis Bein** (University of Hamburg)
- **Edgar Fernando Carrera Jarrin** (Univ. San Francisco de Quito)
- **Adriano Di Florio** (Univ. di Bari e INFN)
- **Ruchi Chudasama** (Tata Institute-B)
- **Emanuele Usai** (Brown Univ.)
- **Meena Meena** (Panjab Univ.)
- **Andreas Albert** (Boston Univ.)
- **Junquan Tao** (IHEP)
- **Claudio Quaranta** (Univ. di Roma I e INFN)
- **Silvio Donato** (Univ. di Pisa e INFN)
- **Varun Sharma** (Univ. of Wisconsin)
- **Valentina Mariani** (Univ. di Perugia e INFN)
- **Oksana Shadura** (Univ. of Nebraska-Lincoln)

Posters

- **Mapse Barroso Ferreira Filho** (Univ. Estado Rio de Janeiro)
- **Andrea Trapote Fernandez** (Univ. de Oviedo)
- **Alejandro Soto Rodriguez** (Univ. de Oviedo)
- **Carlos Vico Villalba** (Univ. de Oviedo)
- **Victor Rodriguez Bouza** (Univ. de Oviedo)
- **Cristina Oropeza Barrera** (Univ. Iberoamericana)
- **Peter Kicsiny** (CERN)
- **Hamed Bakhshiansohi** (Isfahan University of Technology)
- **Suman Chatterjee** (HEPHY)
- **Soumya Mukherjee** (Tata Institute-B)
- **Jona Motta** (LLR, IN2P3-CNRS)
- **Andrea Cardini** (DESY)
- **Alessandro Tarabini** (LLR, IN2P3-CNRS)
- **Amandeep Kaur** (Panjab Univ.)
- **Manuel Alejandro Rodriguez Giraldo** (Univ. de Antioquia)
- **Sahithi Rudrabhatla** (Univ. of Illinois at Chicago)
- **Badder Marzocchi** (Northeastern Univ.)
- **Christopher Mcmahon** (Boston Univ.)
- **Duncan Alexander Leggat** (IHEP)
- **Amandeep Singh Bakshi** (Purdue Univ.)
- **Jyoti Babbar** (Panjab Univ.)
- **Jona Motta** (LLR, IN2P3-CNRS)
- **Mapse Barroso Ferreira Filho** (Univ. Estado Rio de Janeiro)
- **Mintu Kumar** (Tata Institute-A)
- **Si Hyun Jeon** (Seoul National University)

CMS Preliminary Results at LHCP

- Search for Higgs boson pair production in the four b quark final state
  CMS-PAS-HIG-20-005
- Search for high mass trijet resonances using final states with boosted dijet resonances in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-EXO-20-007
- Inclusive and differential cross section measurements of single top quark production in association with a Z boson in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-TOP-20-010
- Measurement of the shape of the b quark fragmentation function using charmed mesons produced inside b jets from tt pair decays
  CMS-PAS-TOP-18-012
- Measurement of the inclusive and differential Higgs boson production cross sections in the decay mode to a pair of τ leptons
  CMS-PAS-HIG-20-015
- Search for flavor-changing neutral current interactions of the top quark and the Higgs boson in the diphoton decay channel in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-TOP-20-007
- Search for charged lepton flavor violation in top quark production and decay in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-TOP-19-006
- Probing effective field theory operators in the associated production of top quarks with a Z boson in multilepton final states at $\sqrt{s}$ = 13 TeV
  CMS-PAS-TOP-21-001
- Search for new particles in events with energetic jets and large missing transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-EXO-20-004
- Measurement of multi-differential cross sections for the production of a Z boson in association with jets in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-SMP-19-009
- Search for long-lived particles decaying into two muons in proton-proton collisions at $\sqrt{s}$ = 13 TeV using data collected with high rate triggers
  CMS-PAS-EXO-20-014
- Search for Higgs boson decays into long-lived particles in associated Z boson production
  CMS-PAS-EXO-20-003
- Search for long-lived particles decaying in the CMS endcap muon system in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-EXO-20-015
- Observation of the B_c^+ meson in PbPb and pp collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
  CMS-PAS-HIN-20-004
- Strange particle collectivity in pPb and PbPb
  CMS-PAS-HIN-19-004
- Luminosity measurement in proton-proton collisions at 5.02 TeV in 2017 at CMS
  CMS-PAS-LUM-19-001
- Measurement of mass dependence of the transverse momentum of Drell Yan lepton pairs in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-SMP-20-003
- Search for resonances decaying to triple W-boson final states in proton-proton collisions at $\sqrt{s}$ = 13 TeV
  CMS-PAS-B2G-20-001

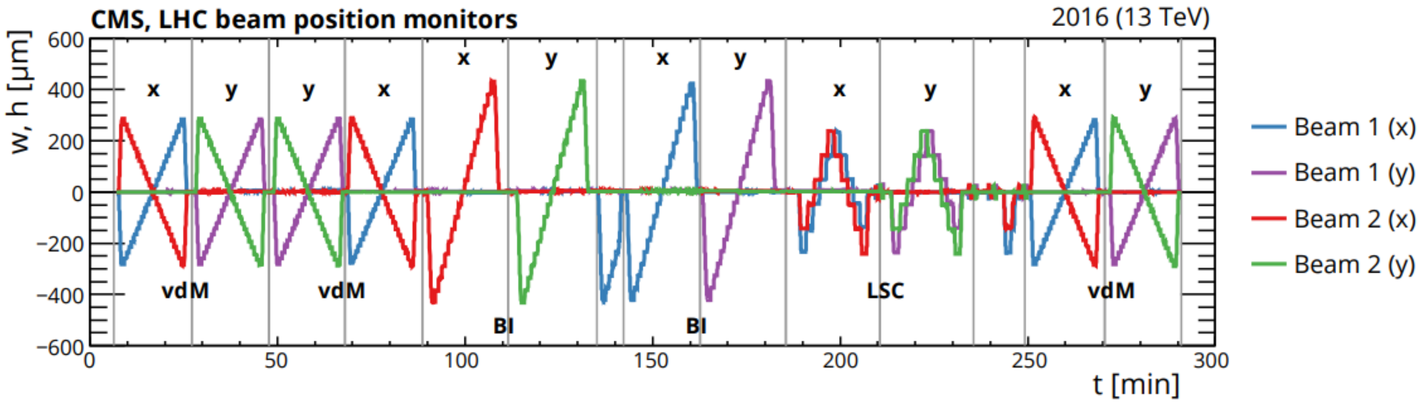
Thank you!

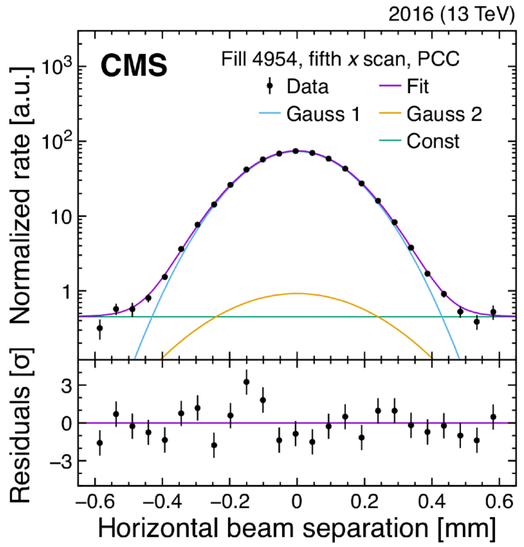

Back up Slides

Precision Luminosity Measurements

Absolute luminosity scale measured for individual bunch crossings

beam-separation
van der Meer scans



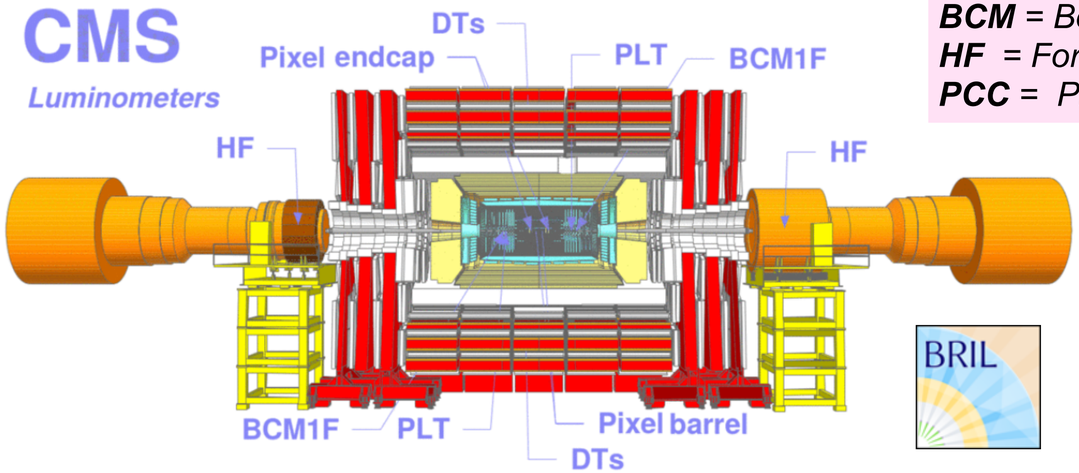


Obtained **relative precision**

- **1.6% in 2015** (2.2 fb^{-1})
- **1.2% in 2016** (36.3 fb^{-1})

Main sources of uncertainties

- differences between measured beam positions and the ones provided by the LHC
- factorizability of the transverse spatial distributions of proton bunches
- modelling of interactions among protons in the colliding bunches



***PLT** = Pixel Luminosity Telescope*
***BCM** = Beam Conditions Monitor*
***HF** = Forward Hadron Calorimeter*
***PCC** = Pixel Cluster Counting*

CMS-LUM-17-003
Submitted to EPJC

Phys. Briefing

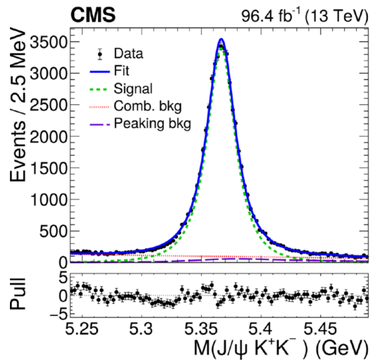
And also:

- 1.9% in 2017 at $\sqrt{s}$ = 5.02 TeV (302 pb^{-1})

CMS-PAS-LUM-19-001

Angular Analysis of $B_s^0 \to J/\psi\,\phi$ Decays

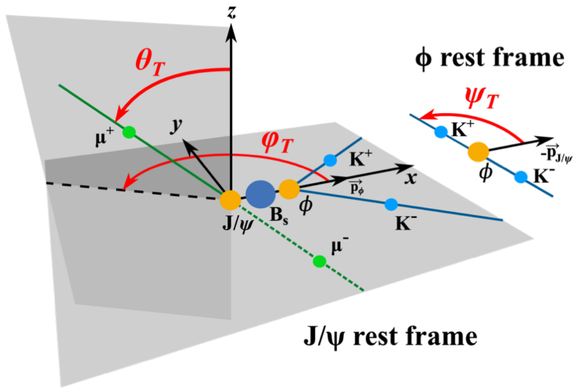
Phys. Briefing

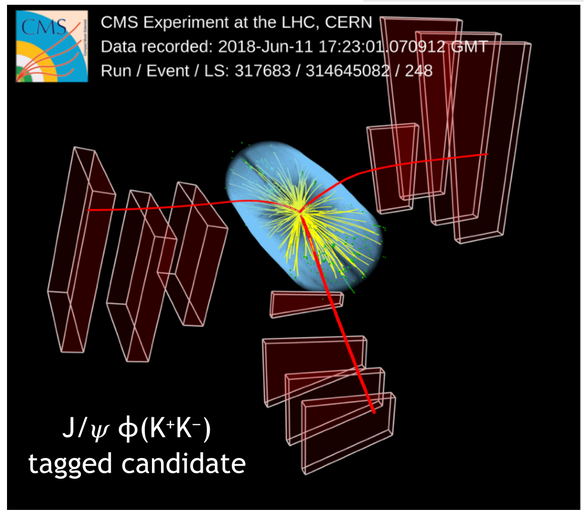


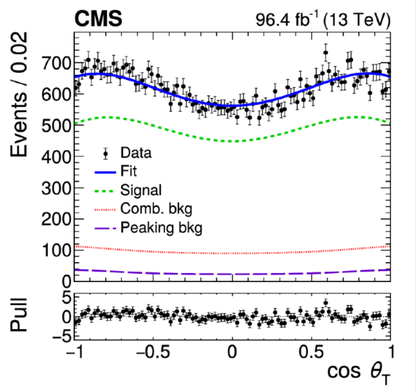
Run-2 2017-18, 96.4 fb^{-1}

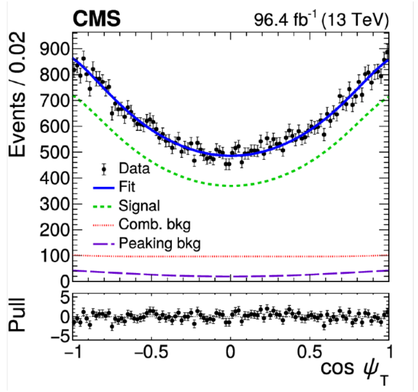
CMS-BPH-20-001
PLB 816 (2021) 136188

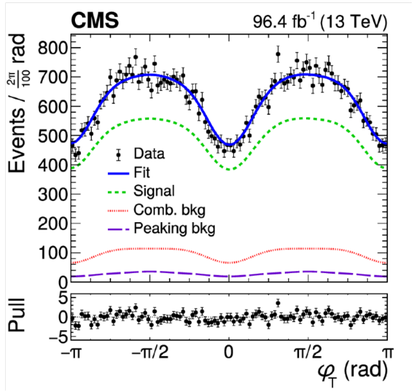
48,500 signal
$B_s^0 \to J/\psi\,\phi(K^+K^-)$ events







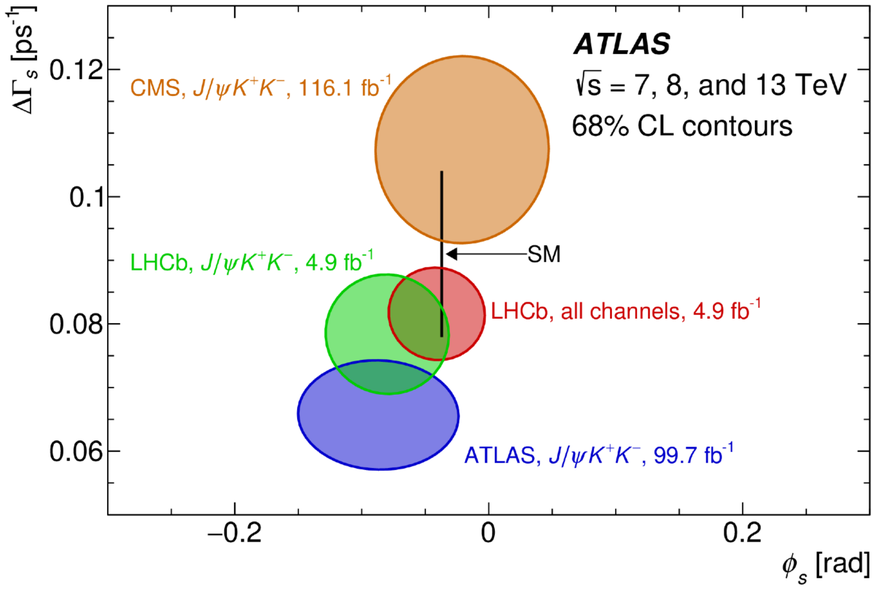




novel opposite-side muon tagger based on deep neural networks (tagging power ~10%)

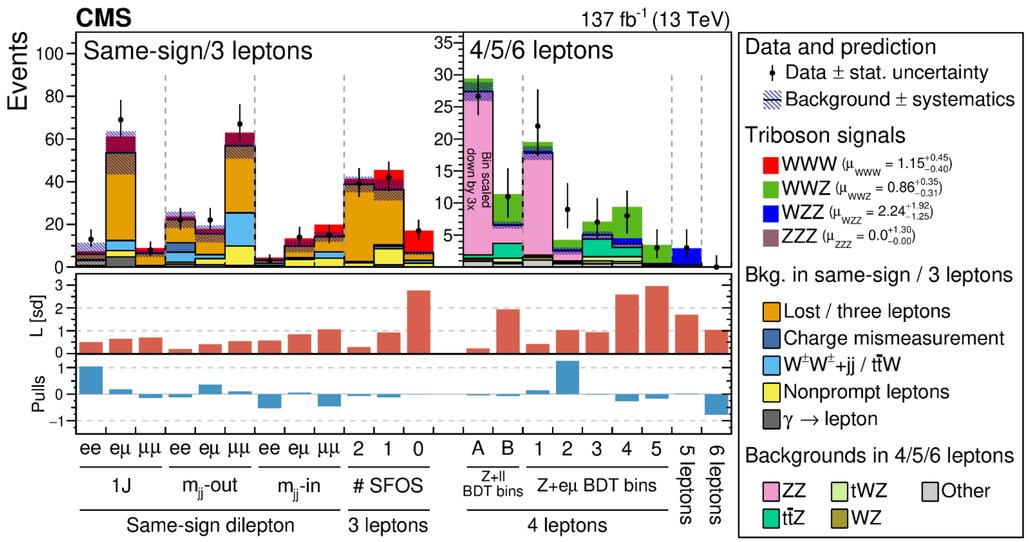
Combining with Run-1 (8 TeV, 19.7 fb^{-1}):

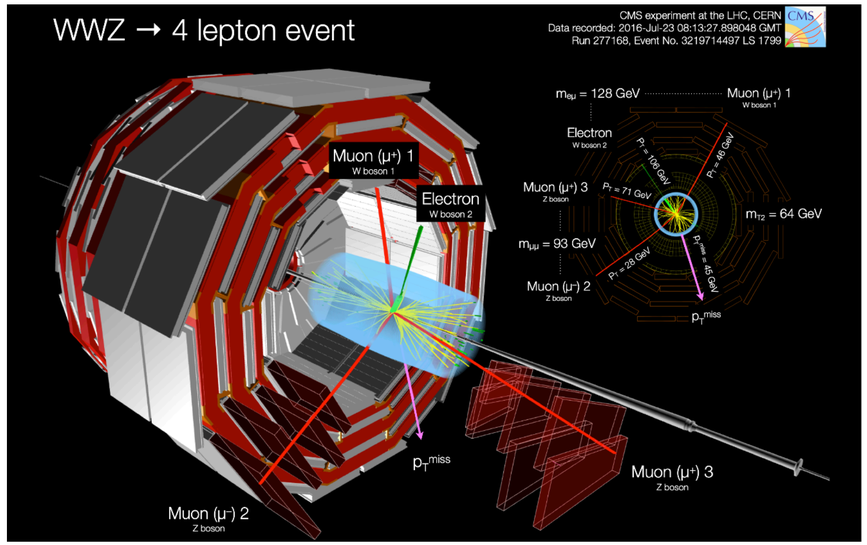
- CP phase:
  $\phi_s = -21 \pm 45$ mrad
- decay width difference:
  $\Delta\Gamma_s = 0.1073 \pm 0.0097$ ps^{-1}



Observation of 3-Boson Production

Leptonic final states



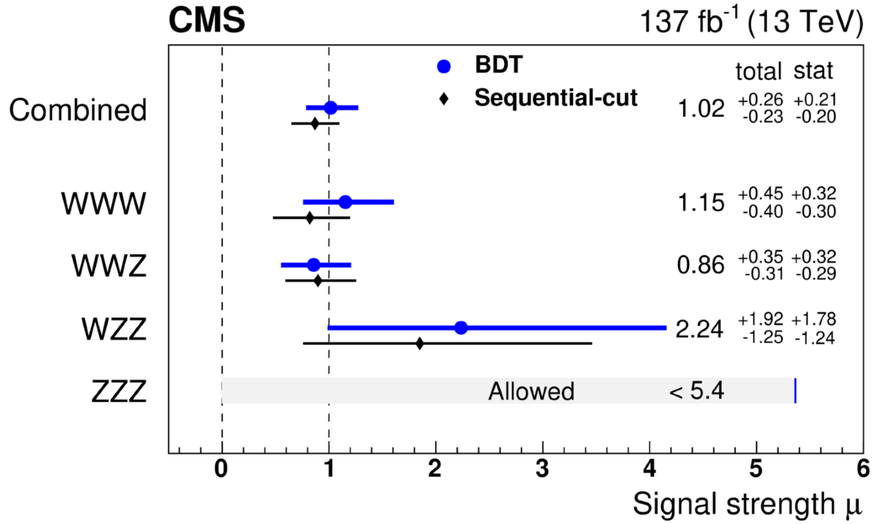


Full Run-2, 137 fb^{-1}

Observation of VVV production (5.7σ), **evidence for WWW and WWZ** (3.3σ)

CMS-SMP-19-014
PRL125 (2020) 151802

Phys. Briefing



Process	Cross section (fb)
Treating Higgs boson contributions as signal	
VVV	$1010^{+210\ +150}_{-200\ -120}$
WWW	$590^{+160\ +160}_{-150\ -130}$
WWZ	$300^{+120\ +50}_{-100\ -40}$
WZZ	$200^{+160\ +70}_{-110\ -20}$
ZZZ	<200
Treating Higgs boson contributions as background	
VVV	$370^{+140\ +80}_{-130\ -60}$
WWW	$190^{+110\ +80}_{-100\ -70}$
WWZ	$100\ ^{+80\ +30}_{-70\ -30}$
WZZ	$110^{+100\ +30}_{-70\ -10}$
ZZZ	<80

ttH Measurements

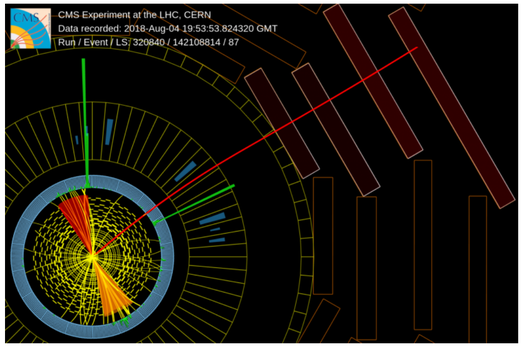
Multi-lepton final states (e, μ, τ_h)

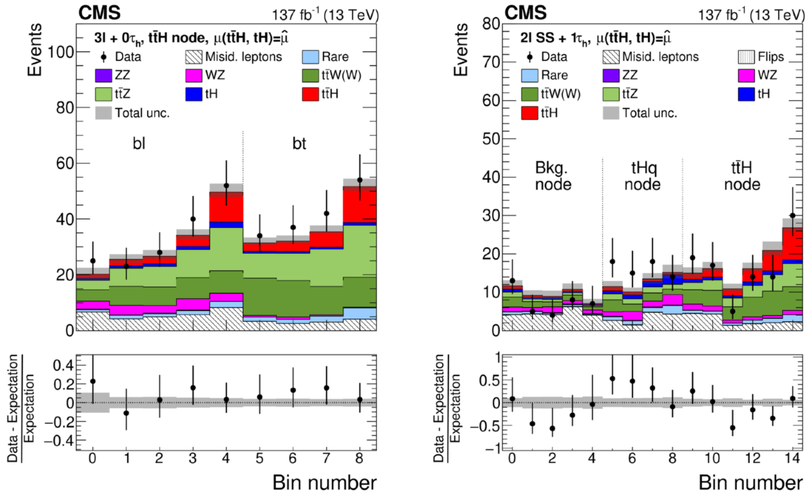
mostly $H \to WW, ZZ, \tau\tau$

CMS-HIG-19-008

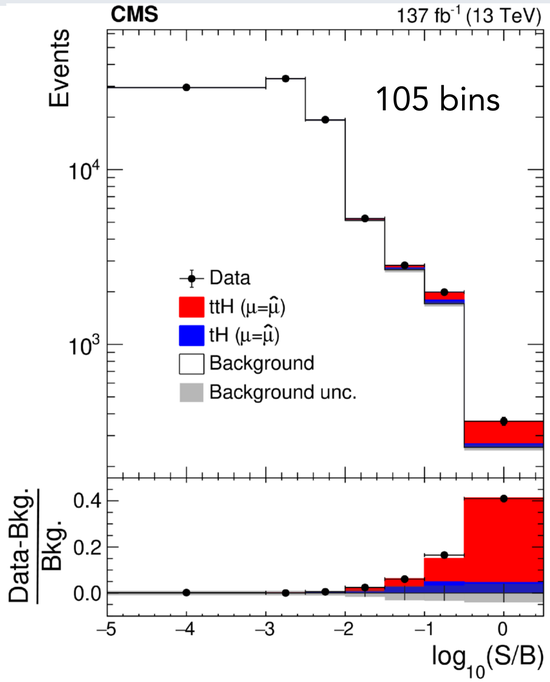
Accepted by EPJC

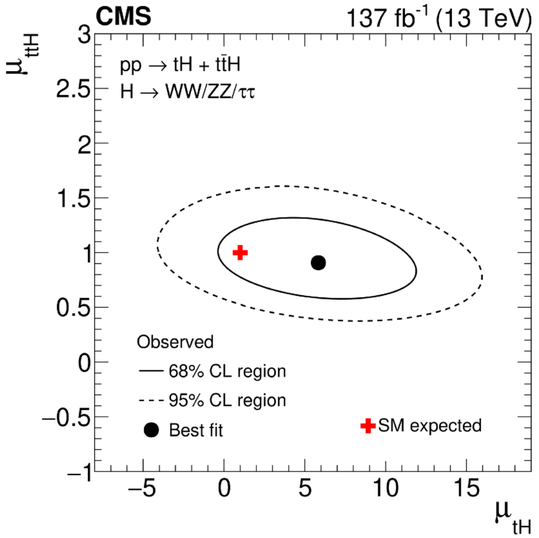
Phys. Briefing



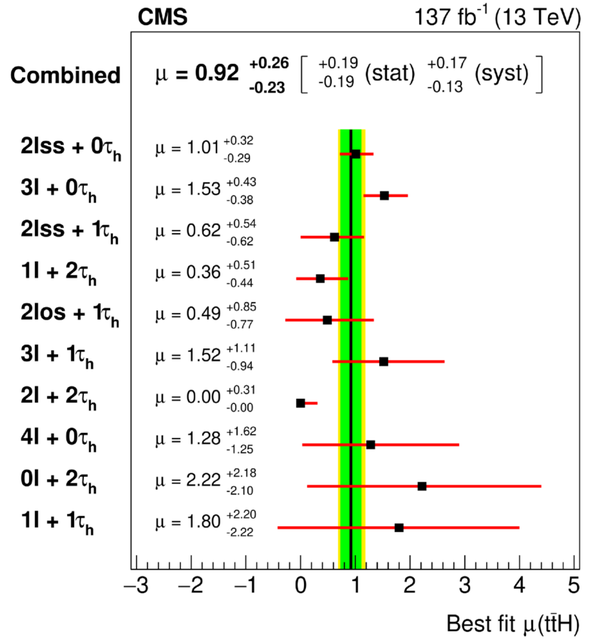


activation value of the ANN output node with the highest activation value





Full Run-2, 137 fb^{-1}



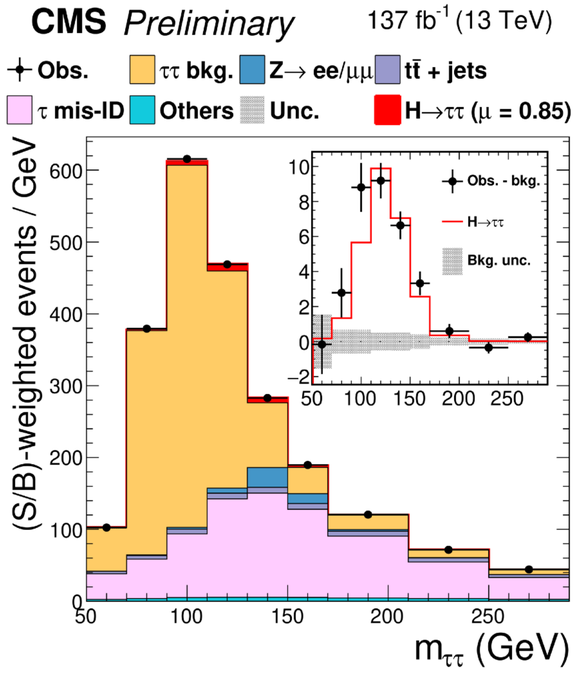
$$\mu(t\bar{t}H) = 0.92 \pm 0.19\,(\text{stat})^{+0.17}_{-0.13}(\text{syst})$$

Obs. (exp.) significance: 4.7 (5.2) σ

$$\mu(tH) = 5.7 \pm 2.7\,(\text{stat}) \pm 3.0\,(\text{syst})$$

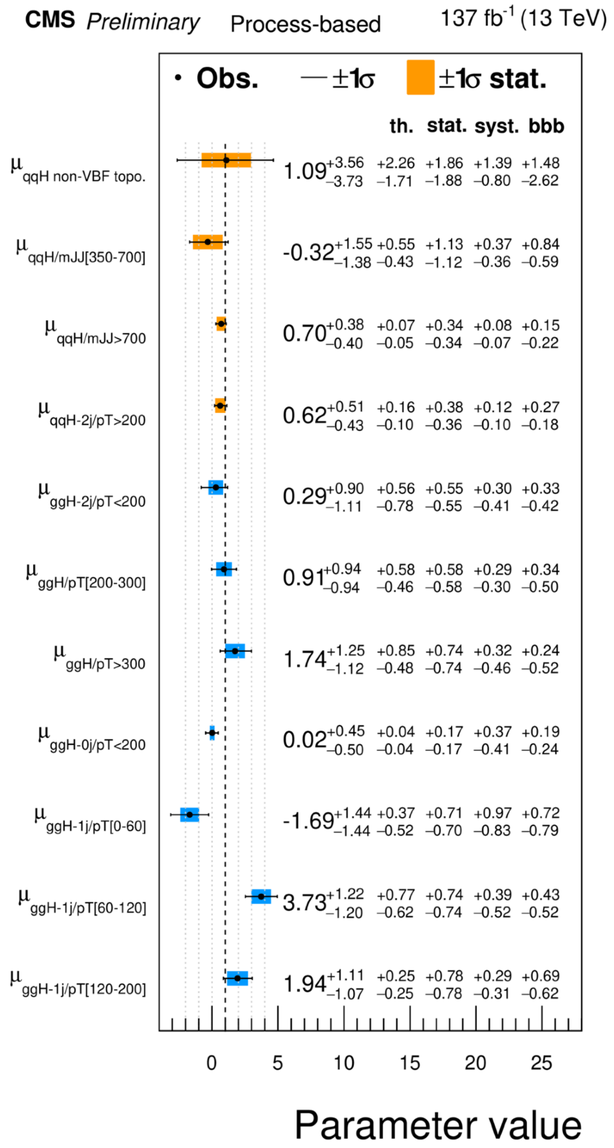
Phys. Briefing

$H \rightarrow \tau\tau$ and STXS

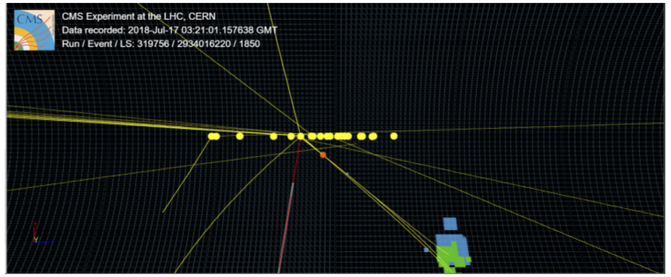


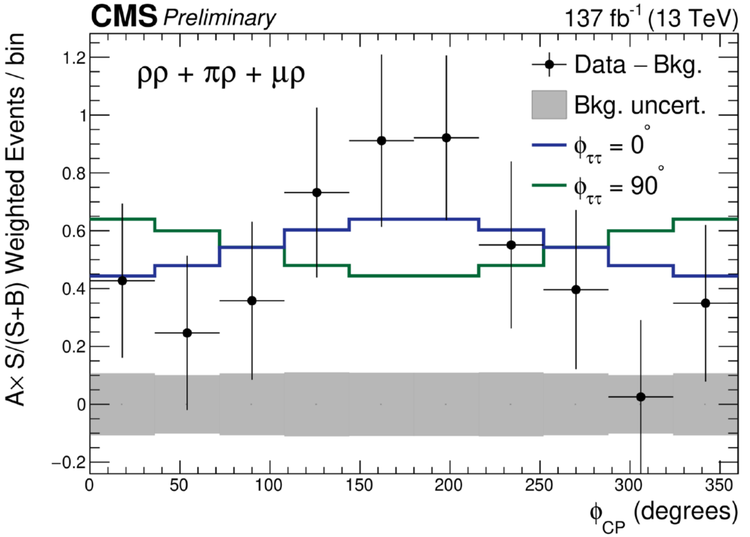
[CMS-PAS-HIG-19-010](#)

[CMS-PAS-HIG-20-006](#)



Full Run-2, 137 fb^{-1}





3.2σ exclusion of pure CP-odd

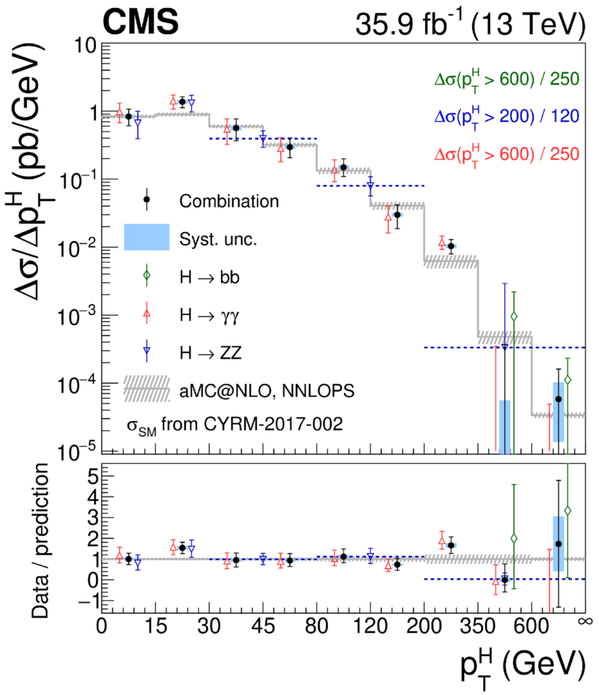
Phys. Briefing

Higgs Differential

Differential distributions unfolded for selection efficiency and resolution effects and compared to theoretical calculations

- $H \to b\bar{b}, \gamma\gamma, ZZ^*$

Run-2 2016, 35.9 fb^{-1}

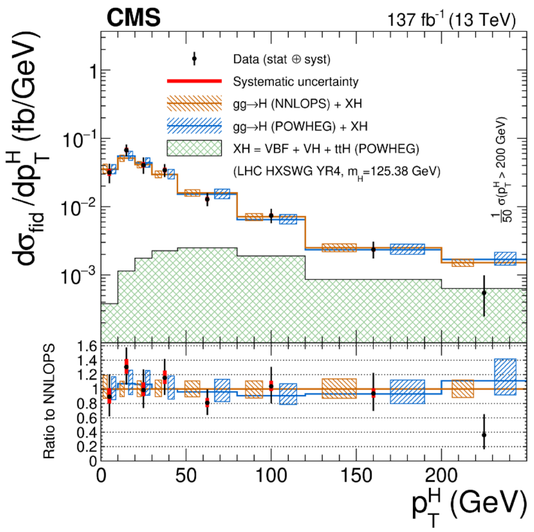


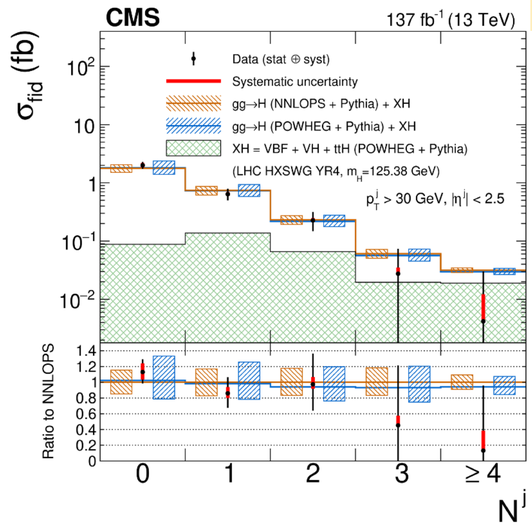
no significant deviation from SM predictions

CMS-HIG-17-028
PLB 792 (2019) 369

- $H \to ZZ^* \to 4\ell$

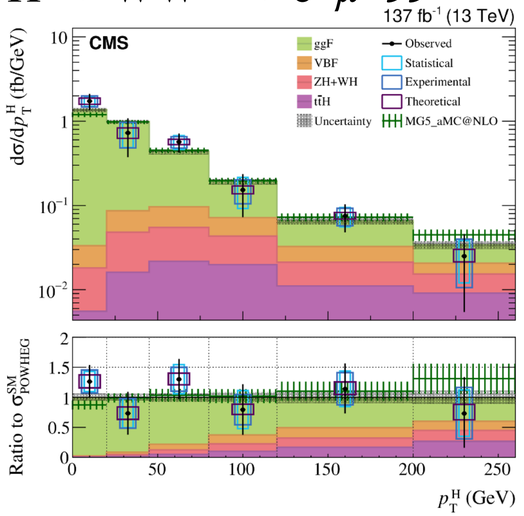
Full Run-2, 137 fb^{-1}

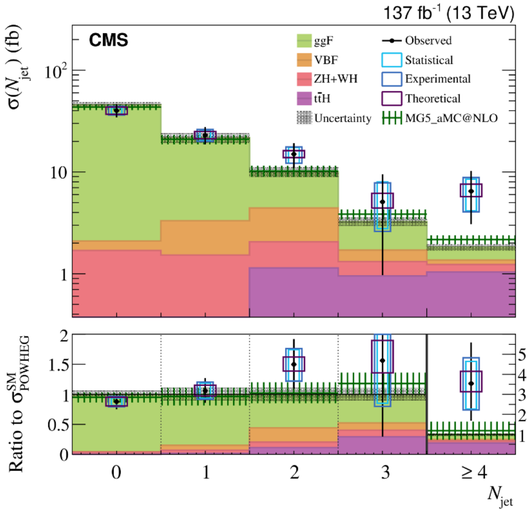




CMS-HIG-19-001
Accepted by EPJC

- $H \to WW^* \to e^{\pm}\mu^{\mp}\nu\bar{\nu}$





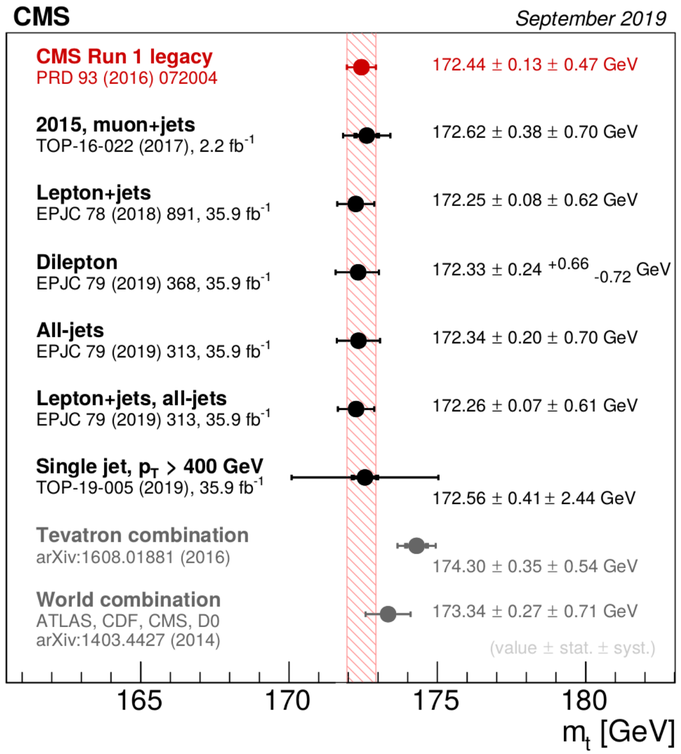
CMS-HIG-19-002
JHEP 03 (2021) 003

Phys. Briefing

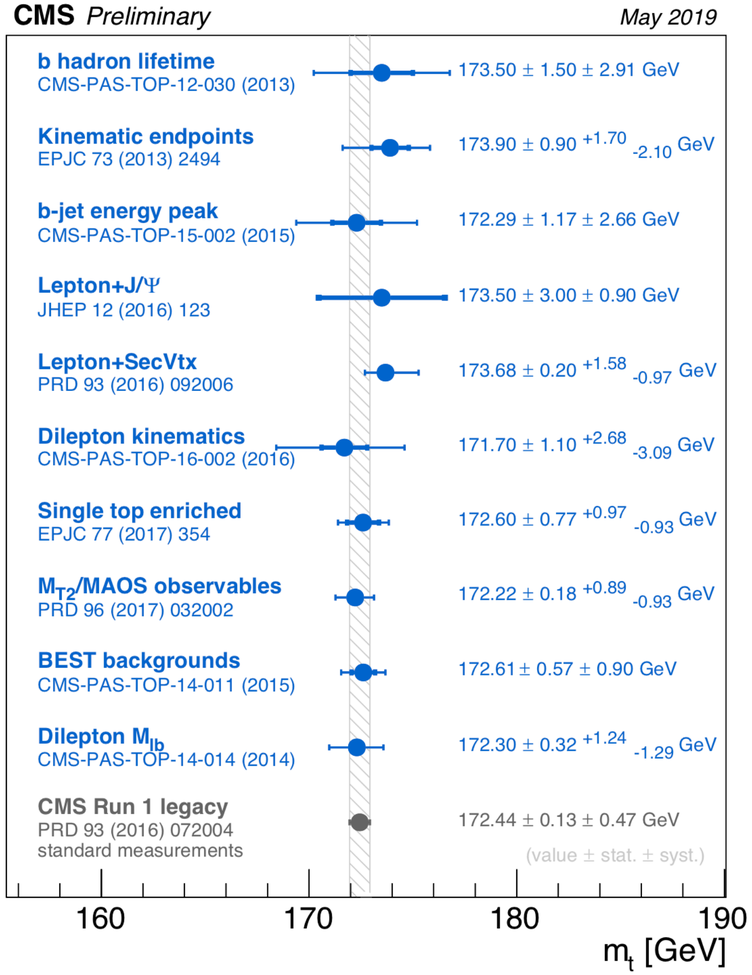
$$\sigma_{\mathrm{fid}}(H \to WW^* \to e^{\pm}\mu^{\mp}\nu\bar{\nu}) = 86.5 \pm 9.5\,\mathrm{fb} \quad (\mathrm{SM}: 82.5 \pm 4.2\,\mathrm{fb})$$

Top-Quark Mass Measurements

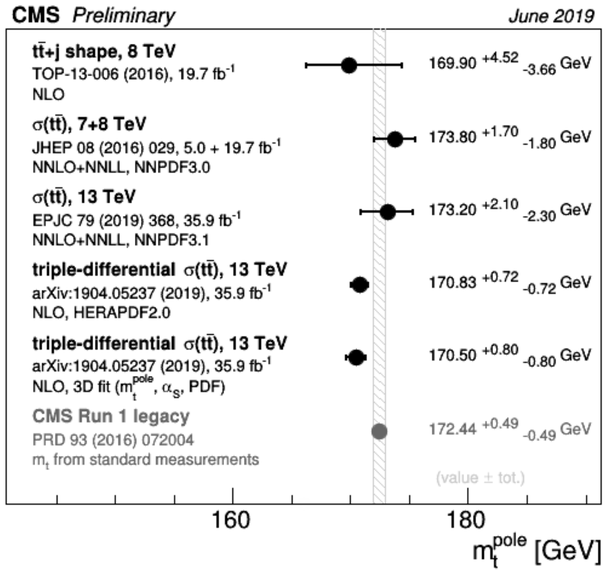
Direct measurements



Alternative measurements



"pole" measurements

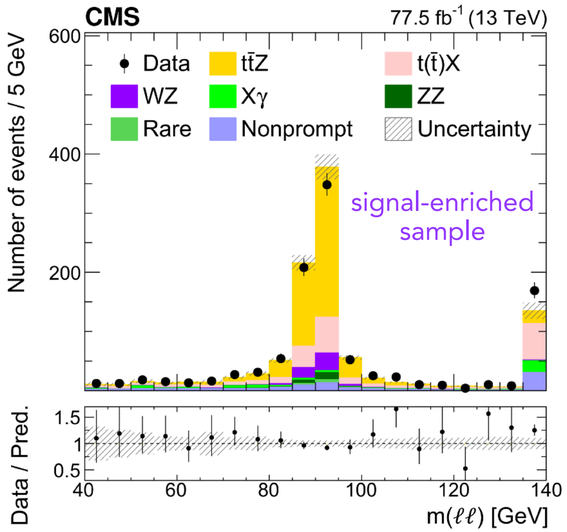


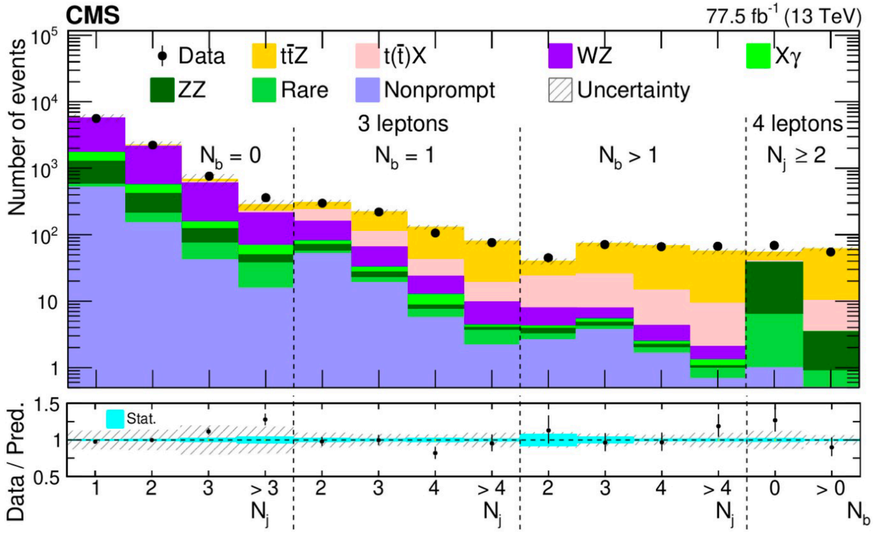
tt+Z and tt+γ

CMS-TOP-18-009
JHEP 03 (2020) 056

Run-2 2016-17, 77.5 fb^{-1}

Events with one Z($\to \ell\ell$) plus at least one lepton (e or μ), $N_j > 0$ and $N_b \geq 0$

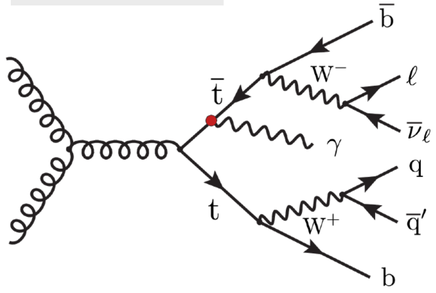




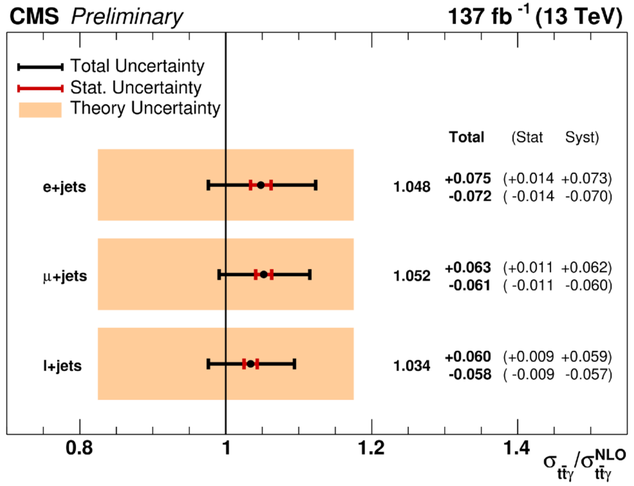
$$\sigma(t\bar{t}Z) = 0.95 \pm 0.05\,(\text{stat}) \pm 0.06\,(\text{syst})\ \text{pb}$$

CMS-PAS-TOP-18-010

Phys. Briefing

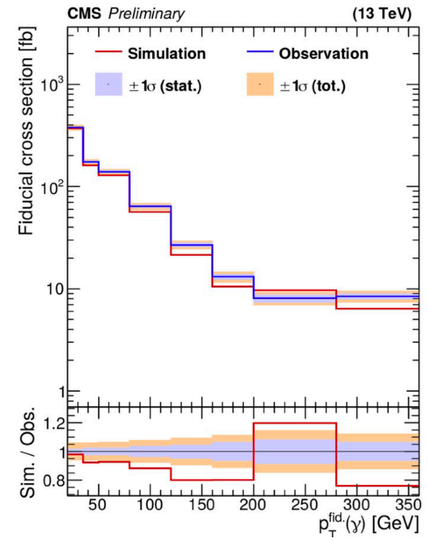


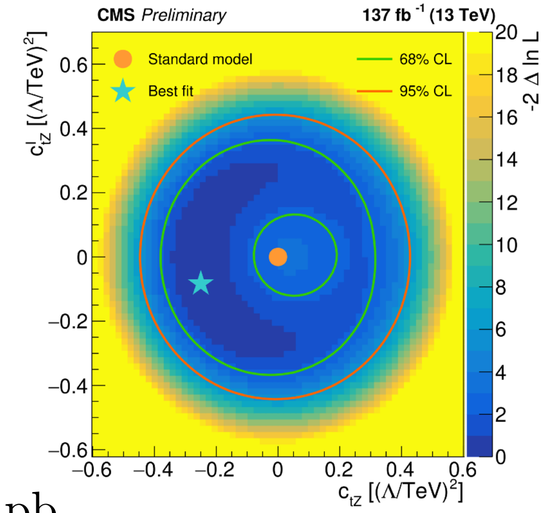
Hard isolated photons in ℓ+jets events



$$\sigma(t\bar{t}\gamma, p_T^{\gamma} > 20\,\text{GeV}) = 0.800 \pm 0.007\,(\text{stat}) \pm 0.046\,(\text{syst})\ \text{pb}$$

Full Run-2, 137 fb^{-1}





Jet Structure in Heavy Ion Collisions

Run-2 $\sqrt{s_{NN}}$ = 5.02 TeV, pp 320 pb^{-1}, PbPb 1.7 nb^{-1}

Study of in-medium modification of jets structure in back-to-back di-jets events in PbPb versus pp collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

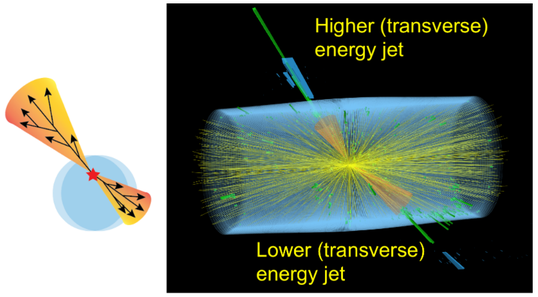
- jet shape (normalised distance to jet axis Δr) in bins of jet unbalance x_j and centrality

Excess of low-pT particles in PbPb compared to pp

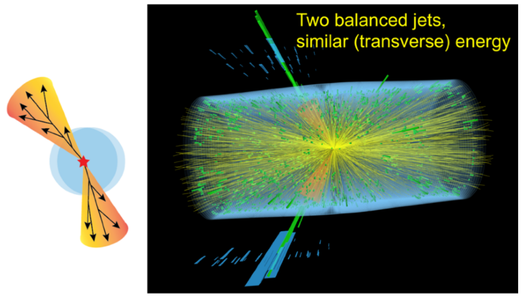
- larger excess in subleading jets

Redistribution of energy from smaller to larger angles in PbPb vs pp

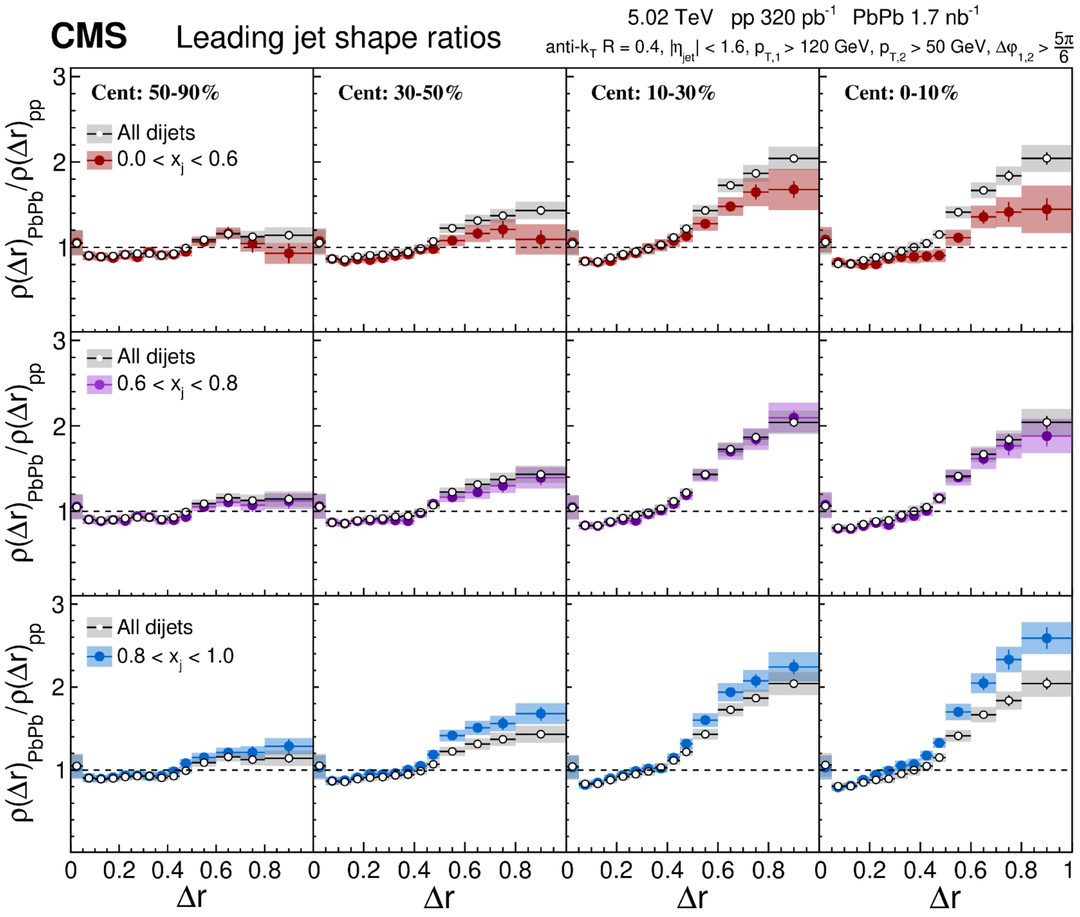
- larger for leading jets



jet balance



centrality

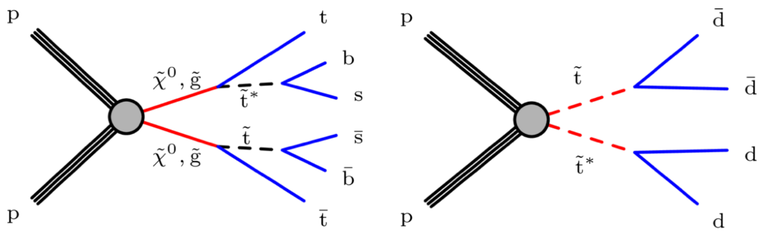


CMS-HIN-19-013
Approved by JHEP

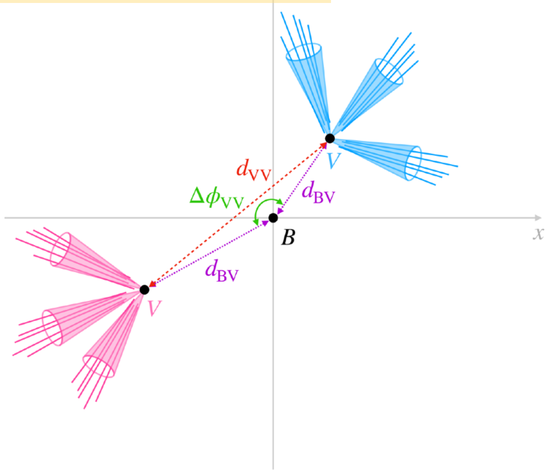
Phys. Briefing

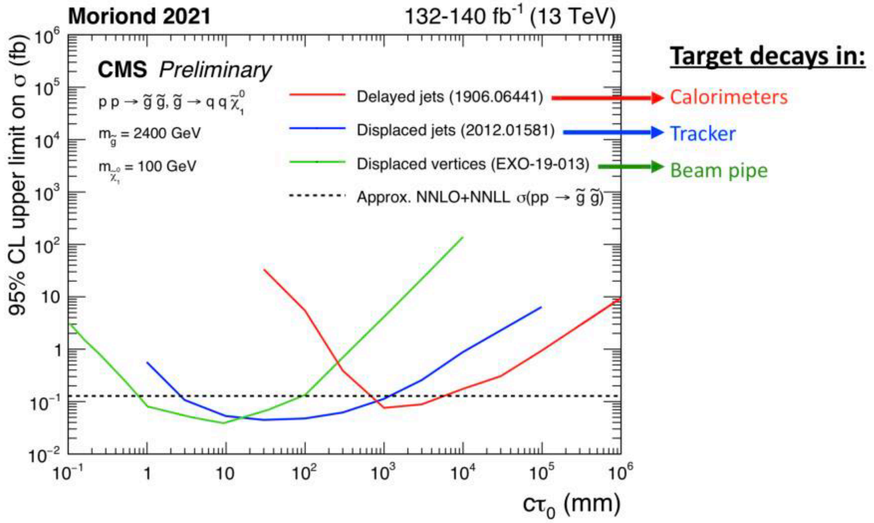
new constraints to the theoretical models

Long-Lived Particles



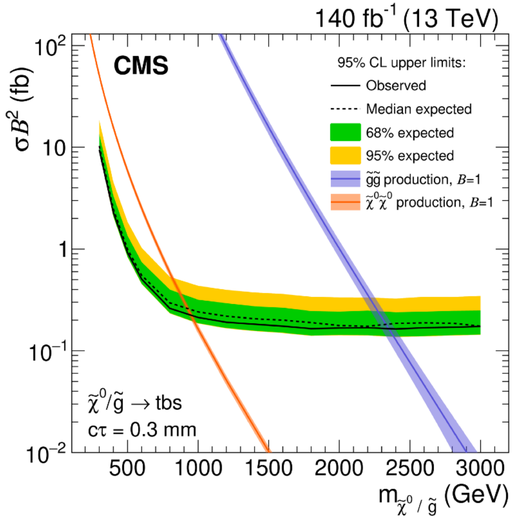
Full Run-2, 140 fb^{-1}

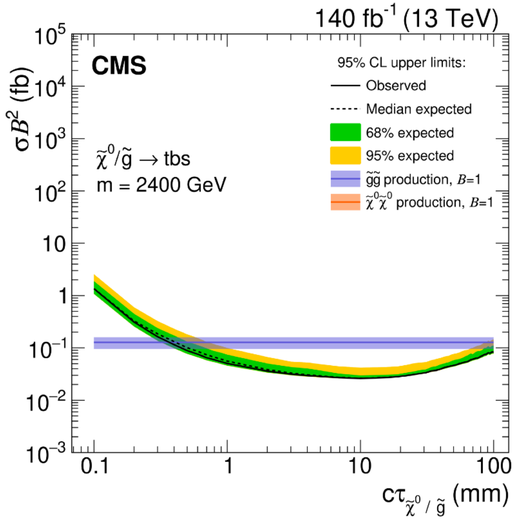




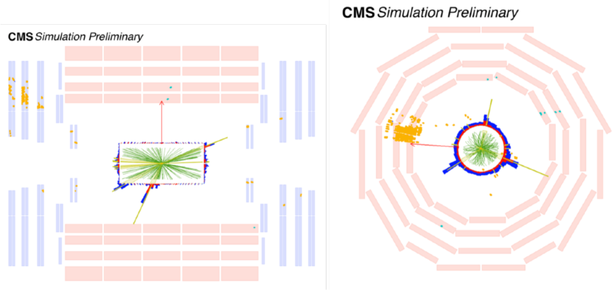
Search for LLPs produced in pairs

- with a mean decay length between 0.1 and 100 mm (i.e. within the beam pipe)
- each decaying into two or more quarks



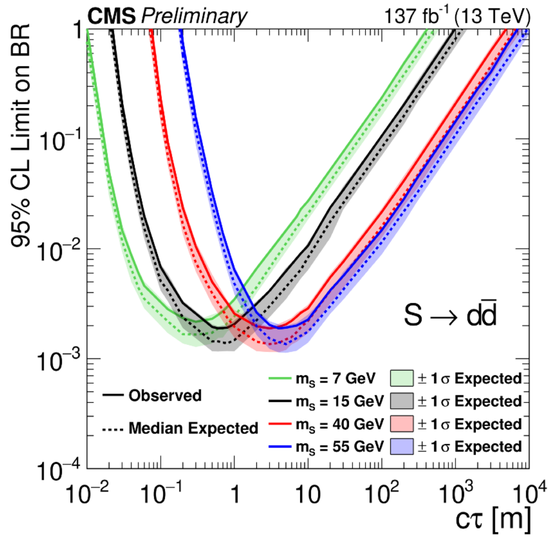


[CMS-EXO-19-013](#)
Submitted to PRD



Search for Higgs boson decaying to long-lived scalars

- decaying to quarks or tau leptons within the forward muon chambers



[CMS-PAS-EXO-20-015](#)