Highlights from the CMS Experiment

Marco Pieri

EPS-HEP 2021

Outline

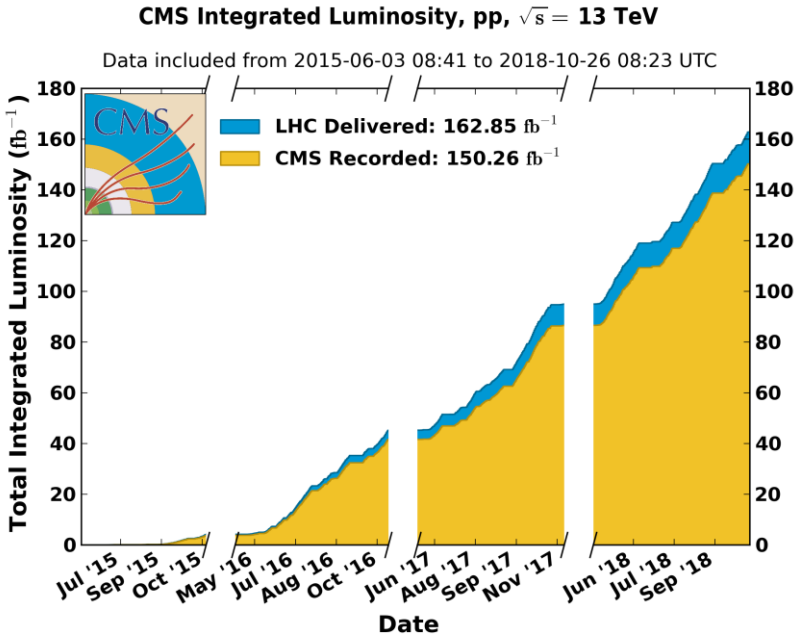
- Run 2 results
  - Physics objects and performance
  - Physics results
- Long Shutdown 2 and preparation for Run 3
- Upgrades and HL-LHC
- Summary

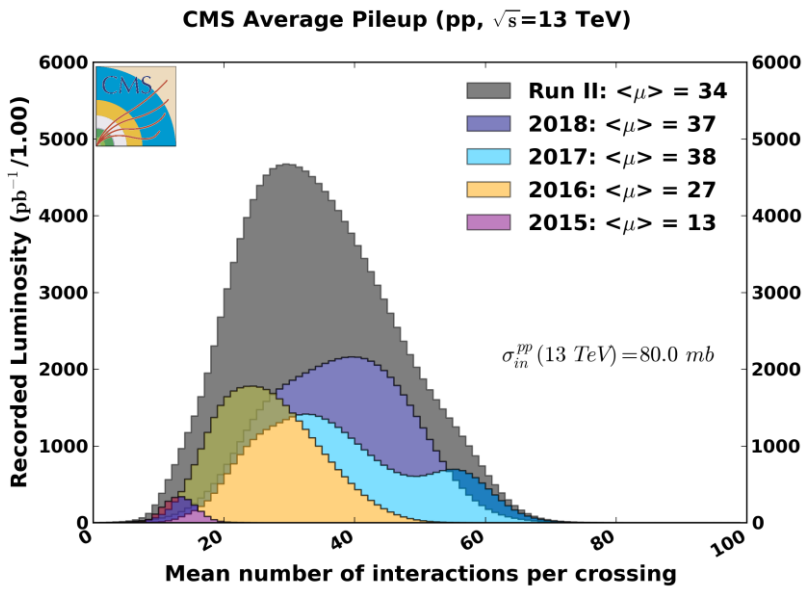
Run 2 analyses

- Run 2 analysis still in full swing
  - Still one of the main priorities in CMS and the physics output continues to be impressive
- We will present 26 new preliminary results here at EPS that were especially prepared for this conference. Only a selection will be shown here
  - Many more and with more details will be shown in the plenary and parallel talks

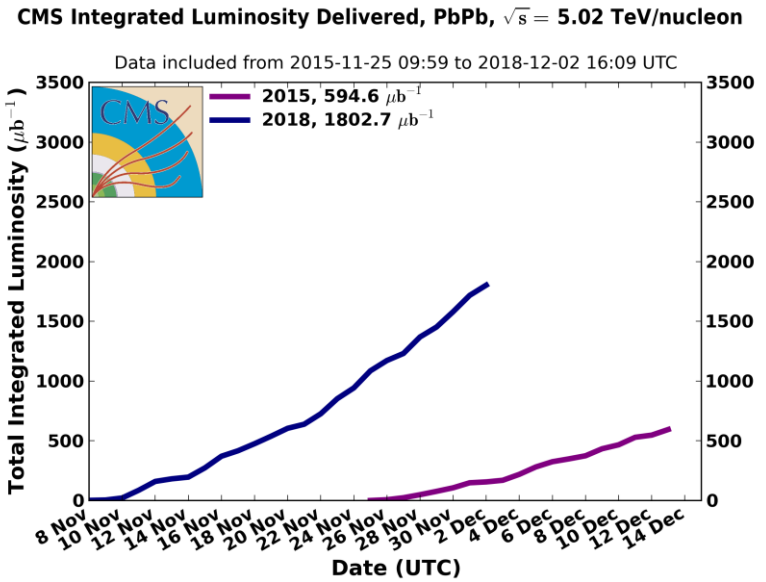
Many thanks to the LHC team for the excellent data they provided to us in Run 1 and Run 2 and for their commitment in view of Run 3

Run 2 ended in 2018 and CMS collected an integrated luminosity good for all physics of almost 140 fb^{-1} at 13 TeV CM energy

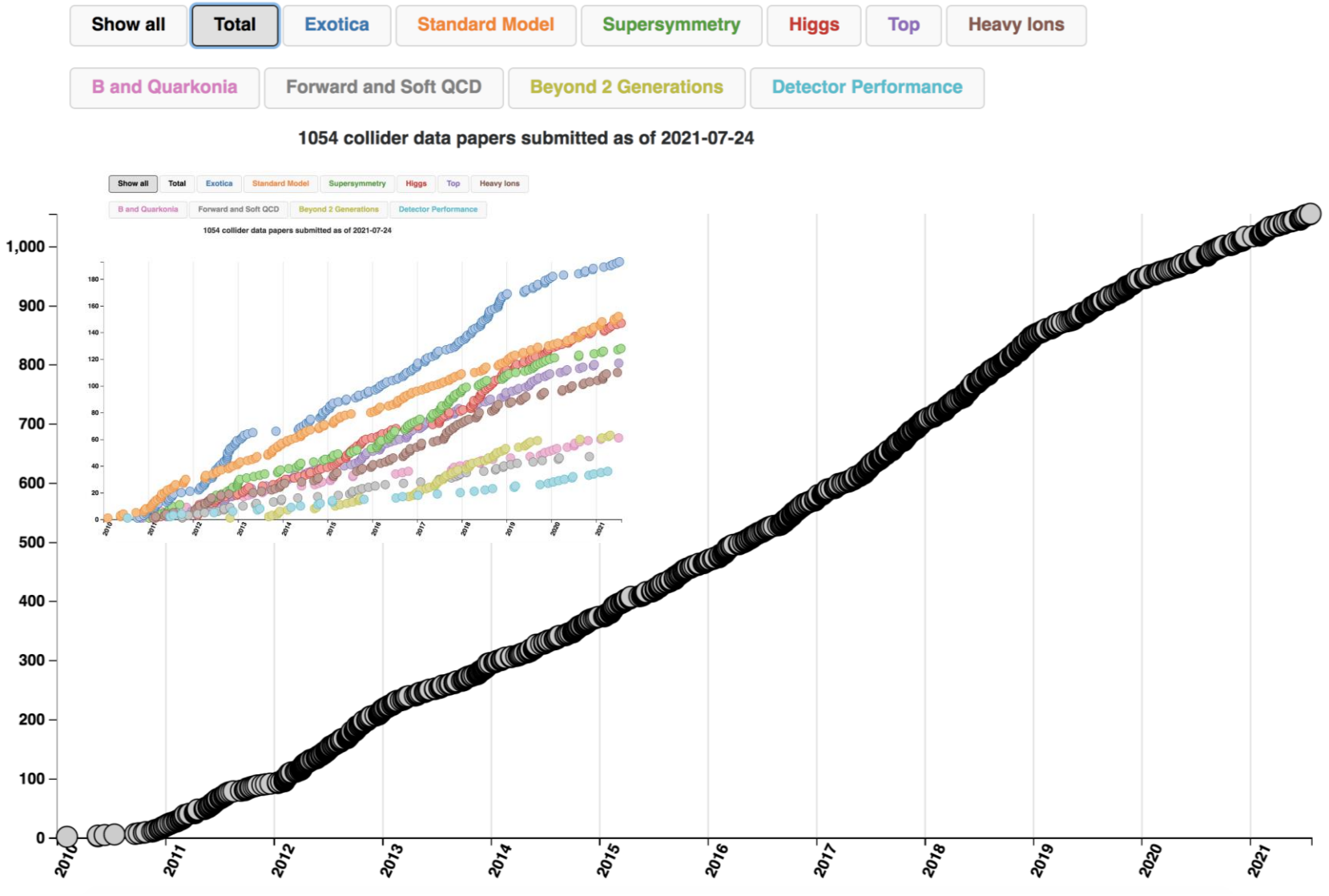




Heavy Ion data, mainly PbPb and pPb



Physics output in terms of publications



- **1054 papers** on collider data published or submitted to a journal
  - 574 based on Run 1 data
  - 474 based on Run 2 data

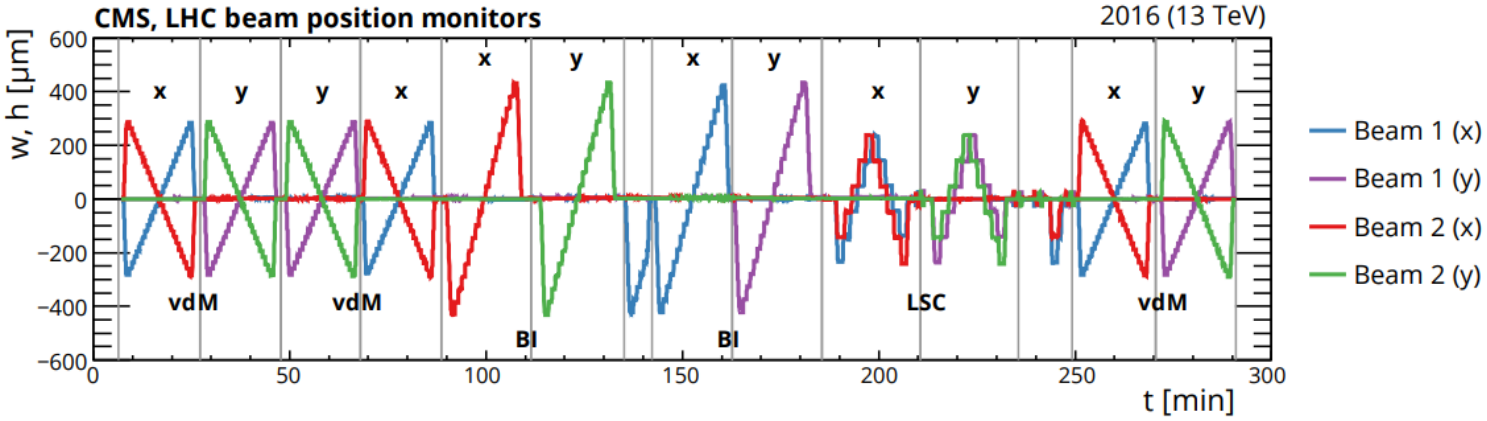
- **More than 1000 published since some time**

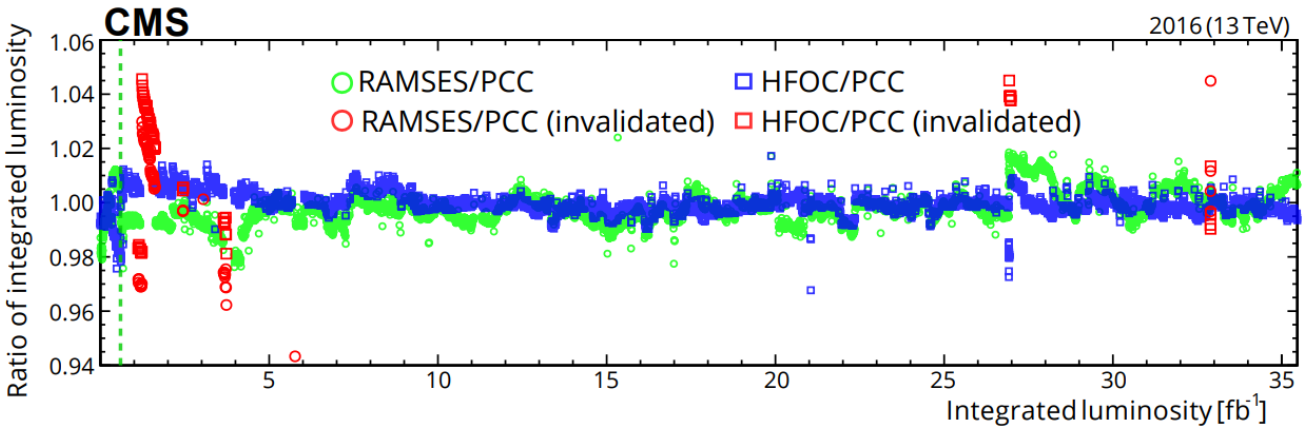
Work on physics objects
Extensive use of Machine Learning
Keep improving performance even in view of Run 3

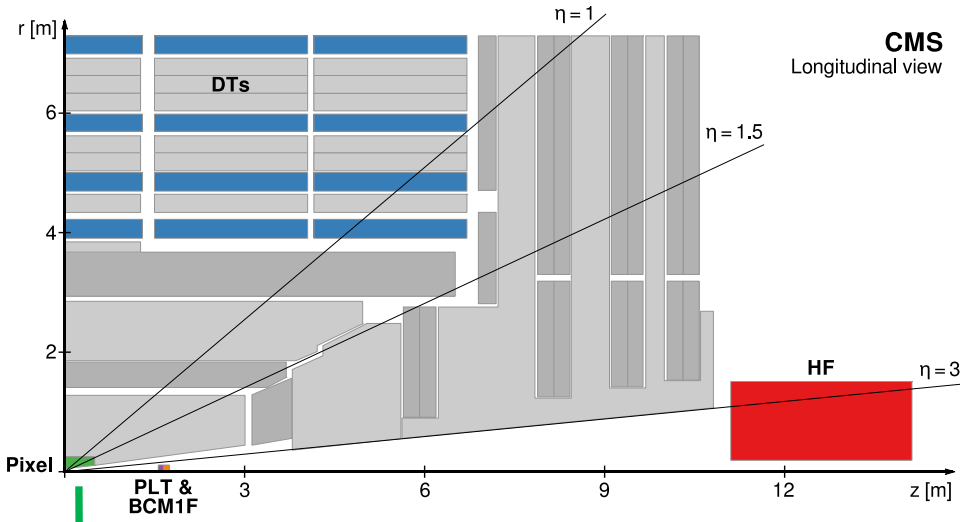
New luminosity analysis of 2015 and 2016

- Ultimate precision for 2015-2016 luminosity
  - Luminosity uncertainty of 2016 **data from 2.5% to 1.2%**
  - Uncertainty full Run 2 data-taking period is 1.6%
  - Updated luminosity for 2017 and 2018 will come soon and reduce even more the overall uncertainty

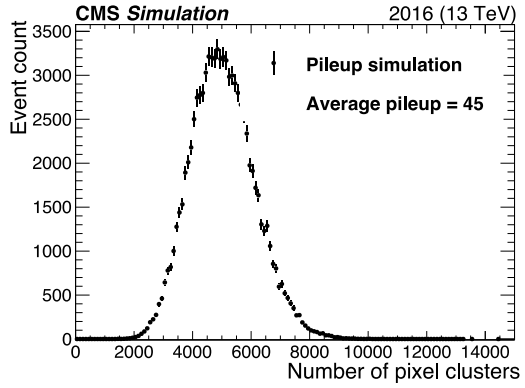
arXiv:2104.01927

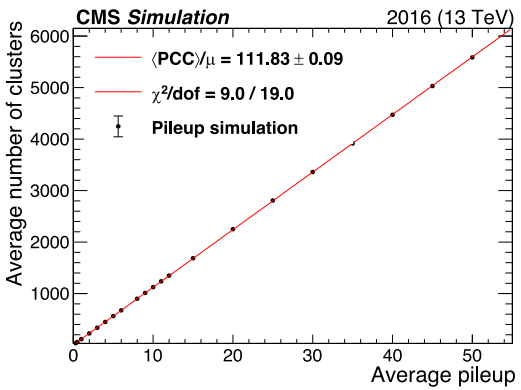






Pixel Cluster Counting (PCC) is the nominal Luminosity measurement method



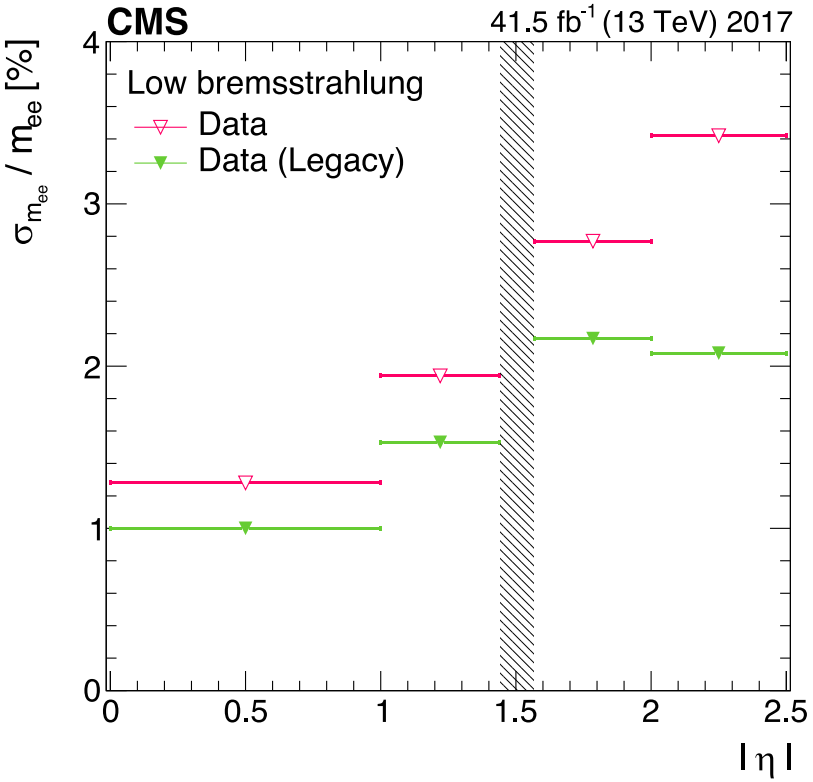


Electron/photon reconstruction and muon trigger

- Publications on Run 2 performance

JINST 16 (2021) P05014

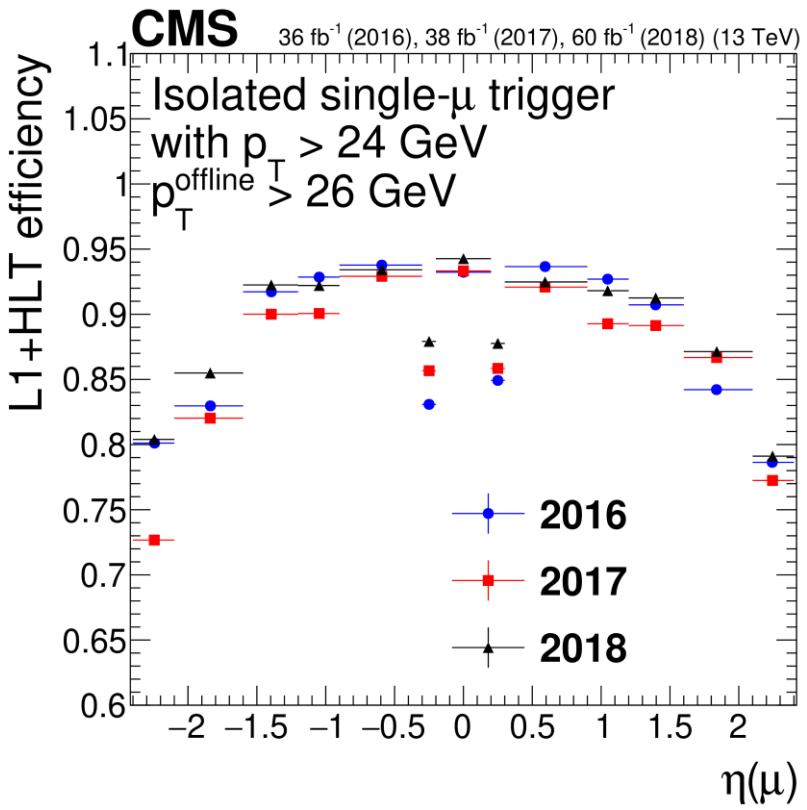
Comparison of Z mass resolution
Before and after final calibration
Included in Legacy Run 2 rereco

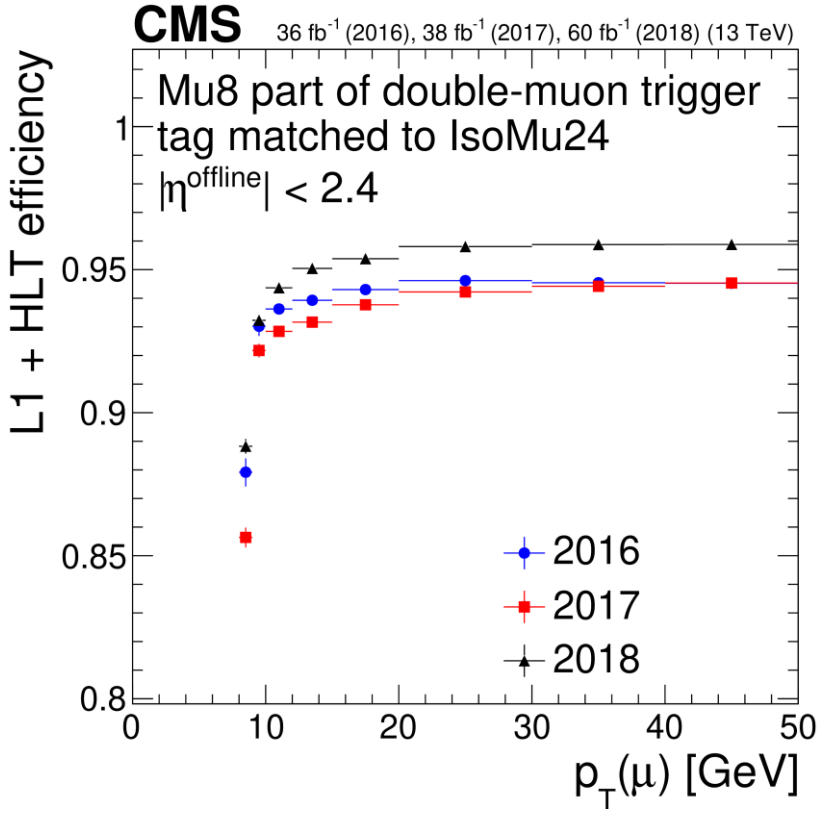


16 (2021) P07001

Performance of the CMS muon trigger system
in proton-proton collisions √s = 13 TeV

Extensive measurements of Run 2 L1 and HLT trigger performance





Recent Physics Results

- All new CMS results that we will be presented at EPS (26), Those in **bold blue** will be featured in this talk

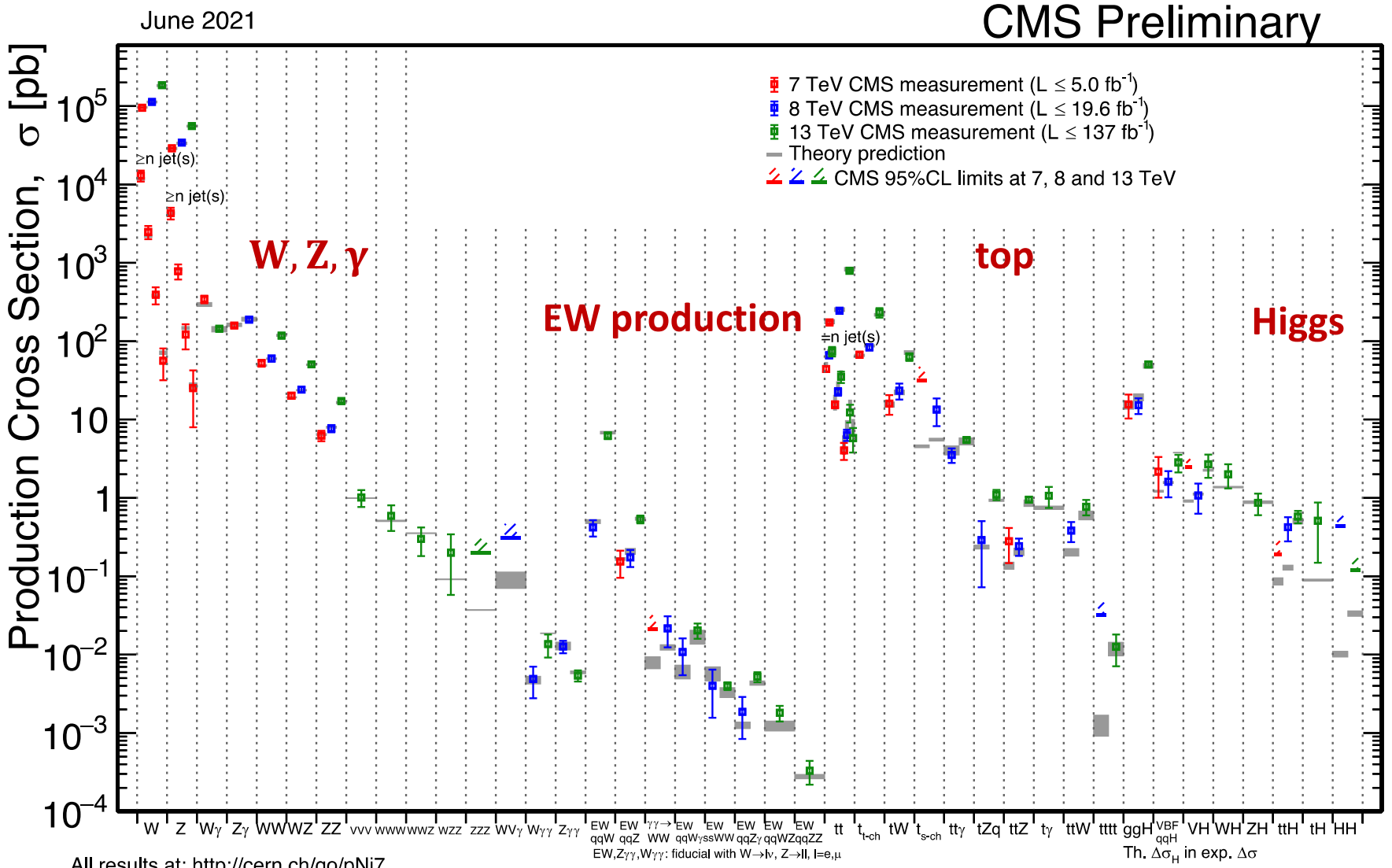
- B2G-20-003: Search for resonant pair production of new particles decaying to pairs of b quarks in the boosted regime
- B2G-20-004: Search for resonant production of HH to 4b in boosted and semi-boosted topologies
- B2G-20-007: Search for resonant production of HH decaying to bb and leptons
- B2G-20-013 Search for diboson resonances in ZV/H to llqq/bb final states including axion-like particles
- B2G-21-001: Nonresonant HH→4b at high invariant HH mass (VBF analysis part)
- **B2G-21-002 Search for resonance decays to triple W-boson in full hadronic final states using 13TeV full Run 2 pp collision data**
- EXO-18-003 Search for displaced leptons in emu, ee, and $\mu\mu$ final states
- EXO-20-002 Search for right-handed W decaying to heavy neutral lepton
- EXO-20-008 Search for excited quarks and Z' decaying into b-jets
- **EXO-20-009: Search for long-lived heavy neutral leptons in leptonic final states**
- EXO-20-013: Search for dark matter in DarkHiggs(WW)+MET dilepton final state
- **HIG-21-003: Search for h->aa in the four photon final state**
- **SUS-20-004: Search for SUSY in HH(4b)+MET final states**
- SUS-21-001: Search for tau sleptons in the all-hadronic final state

- BPH-18-004: Observation of the decays $B^0 \to \psi(2S)K_S^0\pi^+\pi^-$ and $B_s^0 \to \psi(2S)K_S^0$
- **BPH-21-004: Observation of triple J/ψ production**
- **FTR-21-001 WW/WZ VBS HL-LHC**
- **SMP-18-014 Measurement of the Z invisible width – PAS public**
- **SMP-20-011 Inclusive jet measurements at 13 TeV using 2016 data**
- SMP-20-013 WV VBS in the semileptonic channel using full run 2 data
- SMP-20-015 Z+≥1b differential cross sections at 13 TeV
- SMP-21-003: Azimuthal correlations in Z+jets at 13 TeV
- SMP-21-006: Multijet differential cross sections at 13 TeV
- SMP-21-009: Inclusive Jet Cross Section measurements at 5 TeV
- TOP-19-002: FCNC in top quark and Higgs boson interactions (H-bb) (Run 2)
- **TOP-20-005: Search for CP violation in top-pair events with lepton jets channel at 13 TeV (full Run2)**

- All will appear at: http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/CMS/index.html
- See also the CMS Physics Briefings for general public appearing for EPS at: https://cms.cern/tags/physics-briefing

SM measurements

- Measurements of different production processes continue and more and more differential ones
- Check theory calculations, deviations may indicate presence of new physics, EFT interpretations

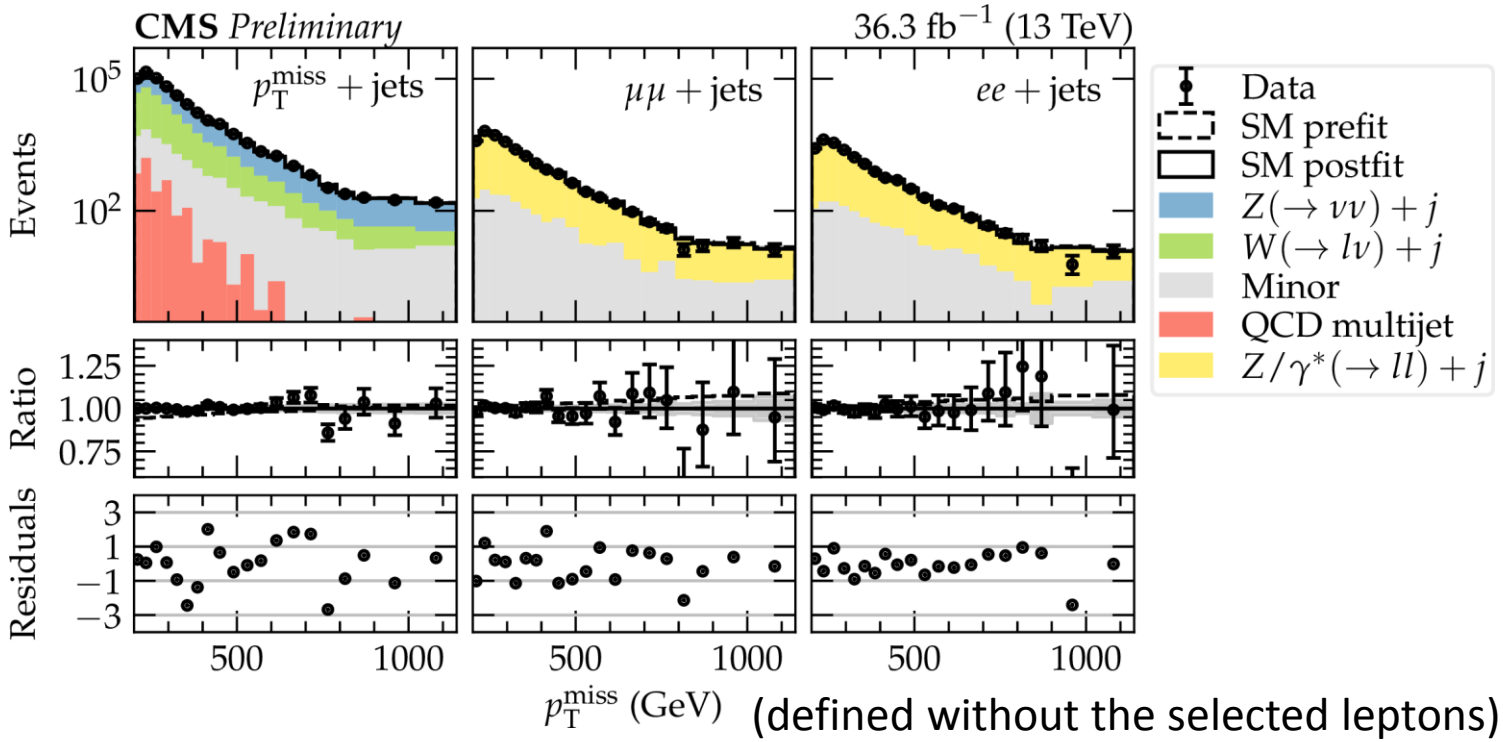


Measurement of the Z invisible width

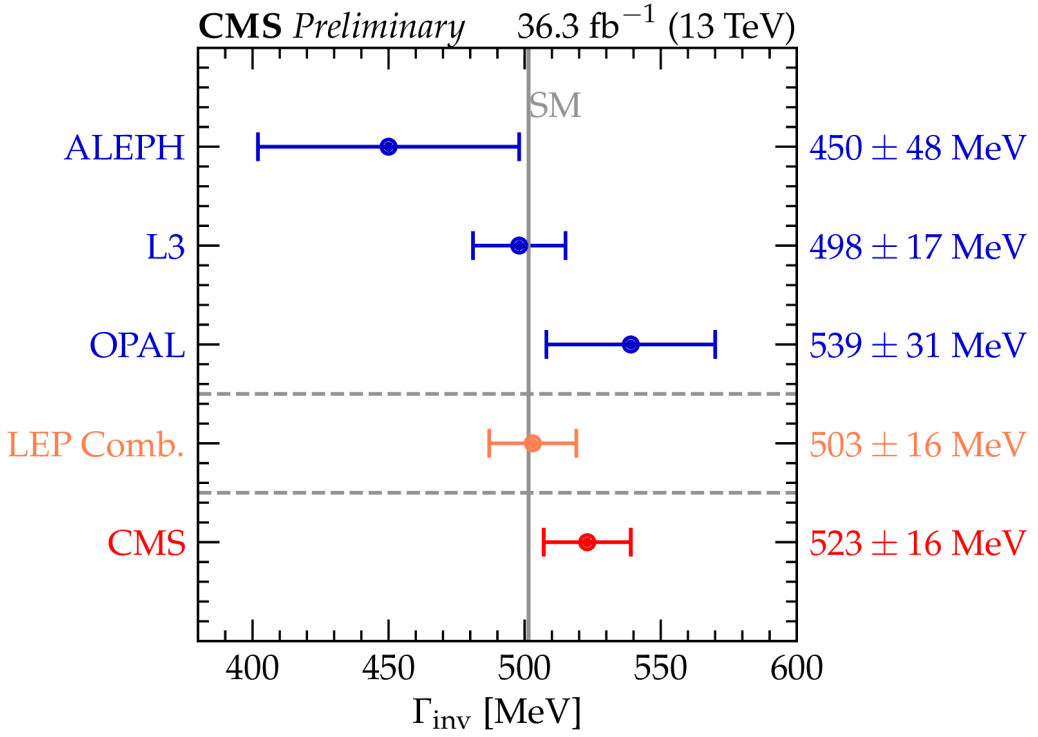
- Uses 2016 13 TeV data

CMS-PAS-SMP-18-014

- Ratio of $\Gamma_{\nu\nu}/\Gamma_{ll}$ from a simultaneous fit if of $Z \to \nu\nu, Z \to \mu\mu$ and $Z \to ee$ enriched categories



(defined without the selected leptons)



- $\Gamma_{inv} = 523 \pm 3$ (stat) $\pm$ 16 (syst) MeV
- Single most precise direct measurement of the Z invisible width Γ_{inv}, competitive with the combined direct LEP result

Talks of Qun Wang (Mon) and Paolo Azzurri (Wed)

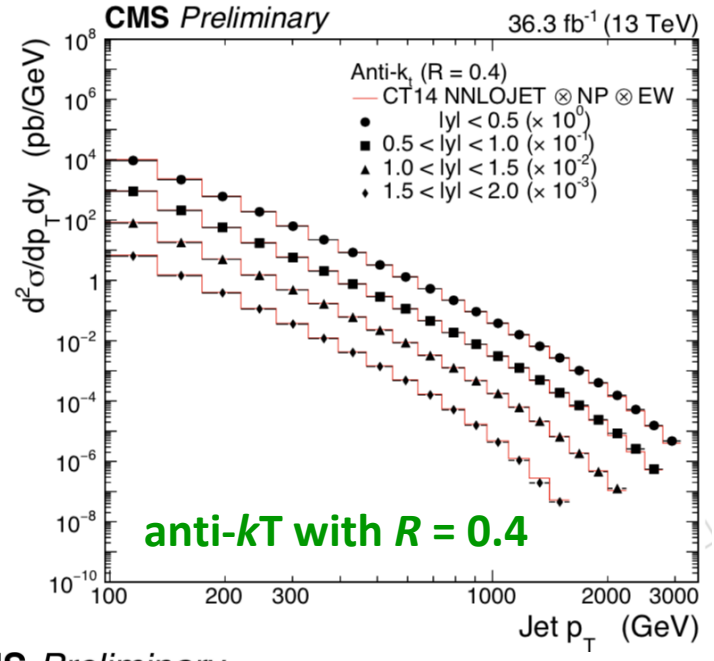
Jet differential distributions

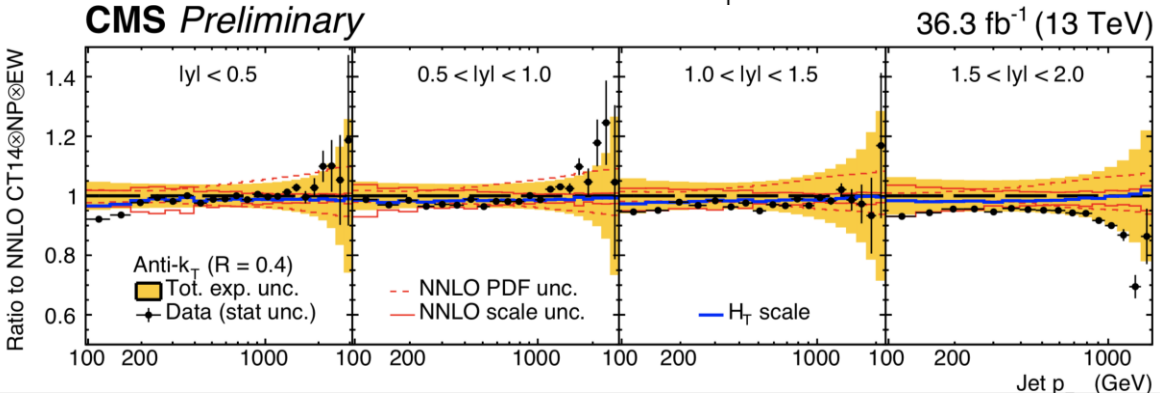
- Several analyses measure multi-differential distributions of inclusive and multi–jet QCD events
- Distributions are unfolded to particle level

CMS-PAS-SMP-20-011

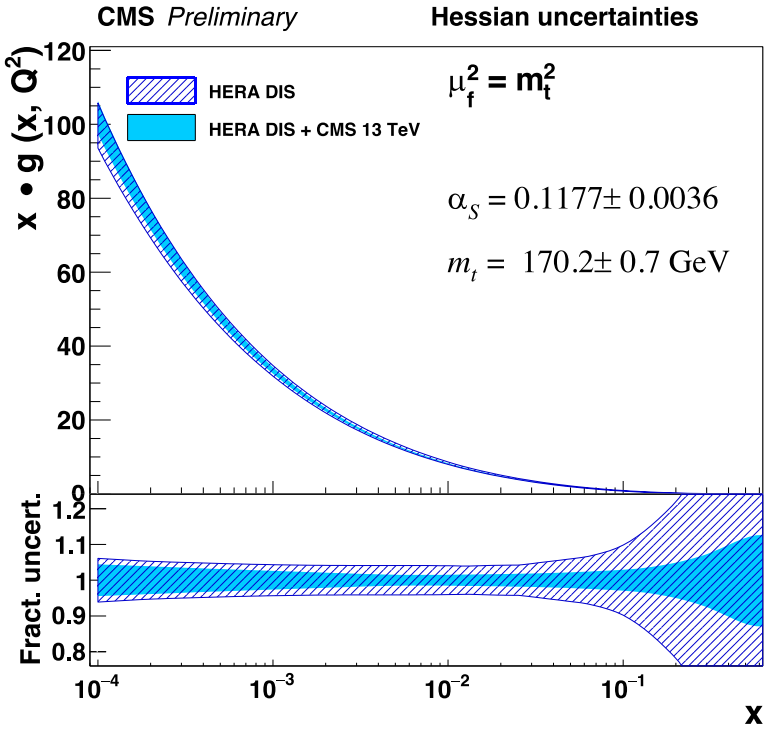
NEW

Inclusive jet cross sections double differential in jet transverse momentum p_T and rapidity y





Improvement in the gluon PDF determination with CMS measurements: jet and tt differential distributions



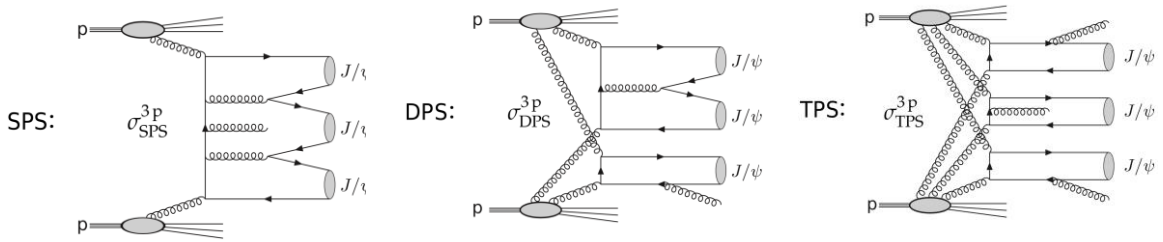
$\alpha_S(m_Z)$ and m_t are also obtained from the fit

Constraints are also derived on SMEFT Wilson coefficients by fitting them together with PDFs, $\alpha_S(m_Z)$ and m_t

Talks of Patrick Connor (Mon) and Paolo Azzurri (Wed)

Observation of triple J/ψ production

- Contributions to the production from single (SPS), double- (DPS), and triple- (TPS) parton scattering:



3 prompt J/ψ

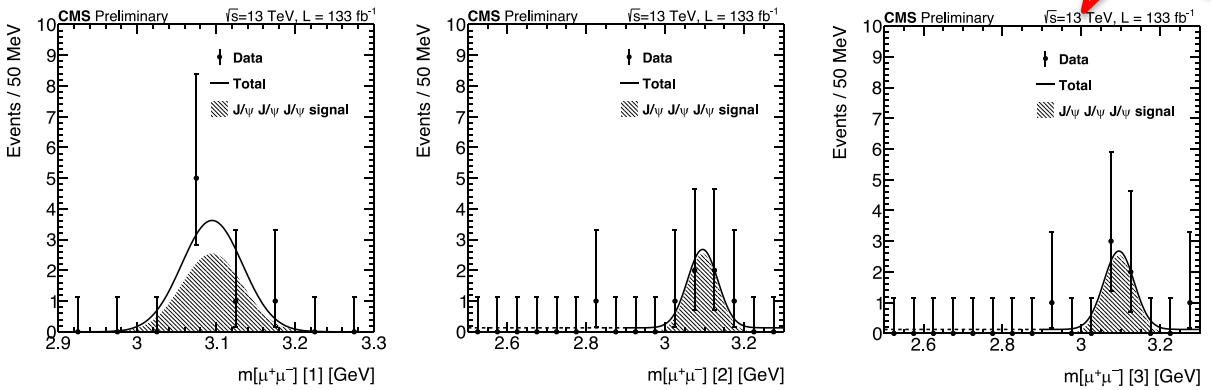
CMS-PAS-BPH-21-004

- Fiducial cross section:

$\sigma(\mathrm{pp} \to \mathrm{J/\psi\ J/\psi\ J/\psi}\ X) = 272^{+141}_{-104}(\mathrm{stat}) \pm 27\ (\mathrm{syst})$ fb

Three J/ψ candidates in each event ordered by p_T

NEW



First observation of triple J/ψ production with >5 σ significance

- Production is expected to be dominated by DPS and TPS contributions, the DPS associated effective cross section parameter is:

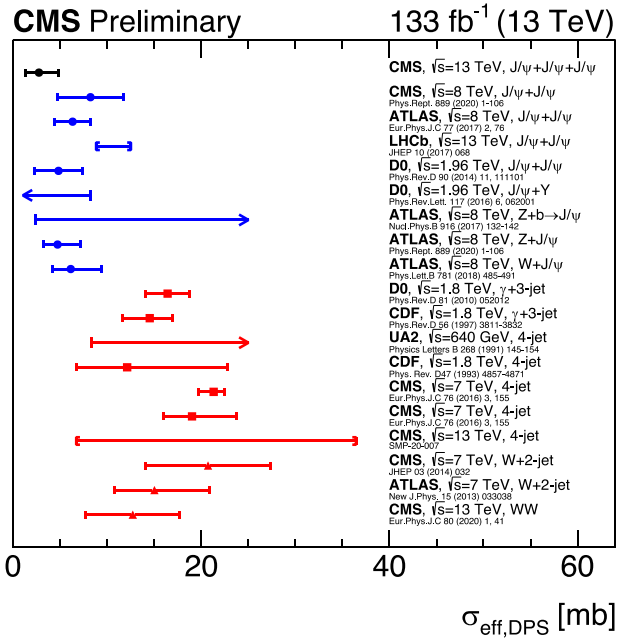
$\sigma_{Eff,DPS} = 2.7^{+1.4}_{-1.0}(\mathrm{exp})^{+1.5}_{-1.0}(\mathrm{theo})$ mb

where $\sigma_{Eff.DPS}$ is an effective interaction area:

$$\sigma_{\mathrm{DPS}}^{\mathrm{pp}\to\psi_1\,\psi_2+X} = \left(\frac{m}{2}\right) \frac{\sigma_{\mathrm{SPS}}^{\mathrm{pp}\to\psi_1+X}\,\sigma_{\mathrm{SPS}}^{\mathrm{pp}\to\psi_2+X}}{\sigma_{\mathrm{eff,DPS}}}$$

- **Candidate channel for first observation of TPS**

Measured $\sigma_{Eff,DPS}$ compared to the same measurement in other processes



Talks of Maxim Pieters (Mon) and Paolo Azzurri (Wed)

Search for CP violation in semi-leptonic tt

- Measure asymmetry of 4 T-odd observables which if CPT is conserved are also odd under CP transformation

$$O_3 = Q_\ell \epsilon(p_b, p_{\bar{b}}, p_\ell, p_{j_1}) \propto Q_\ell \vec{p'}_b \cdot (\vec{p'}_\ell \times \vec{p'}_{j_1})$$

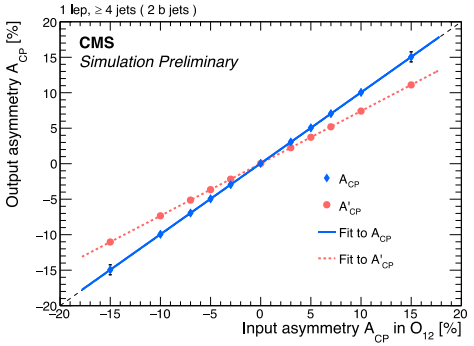
$$O_6 = Q_\ell \epsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j_1}) \propto Q_\ell (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1})$$

$$O_{12} = q \cdot (p_b - p_{\bar{b}}) \epsilon(P, q, p_b, p_{\bar{b}}) \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z \cdot (\vec{p}_b \times \vec{p}_{\bar{b}})_z$$

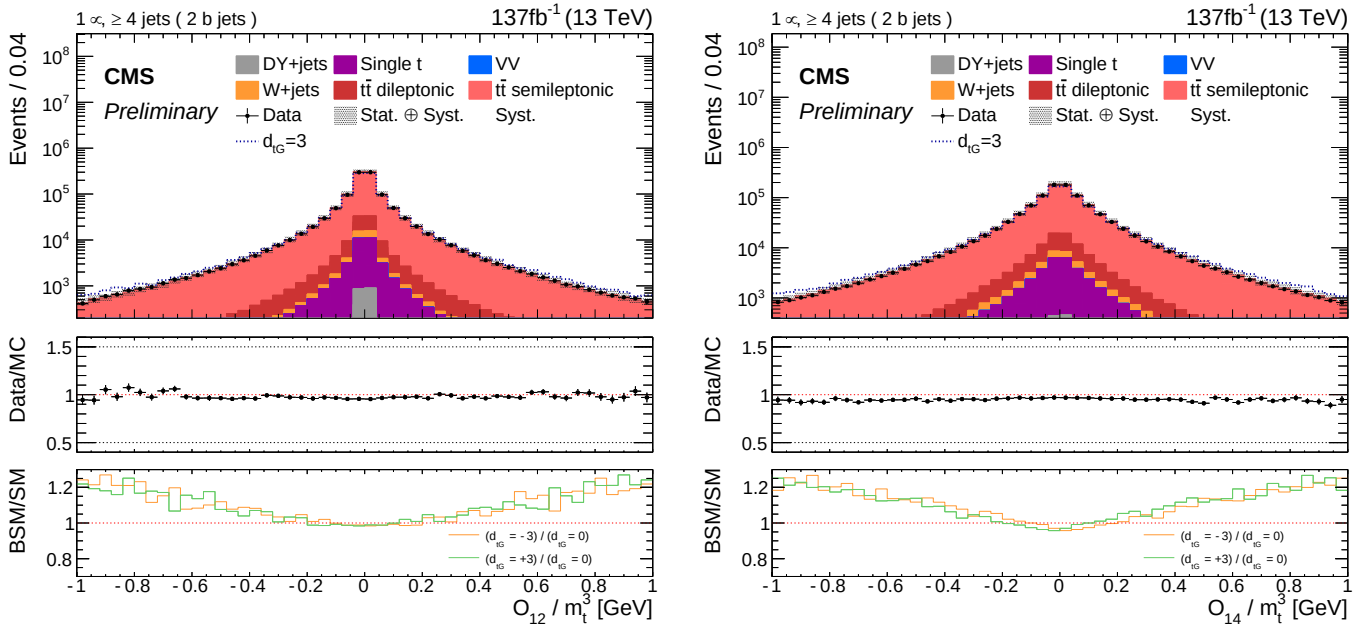
$$O_{14} = \epsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j_1}) \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1}).$$

$$A_{CP}(O_i) = \frac{N_{\text{events}}(O_i > 0) - N_{\text{events}}(O_i < 0)}{N_{\text{events}}(O_i > 0) + N_{\text{events}}(O_i < 0)}, i = 3, 6, 12, 14$$

Measured asymmetries A'_{CP} are affected by dilution effects
Due for example to the mis-assignment of the quark/antiquark

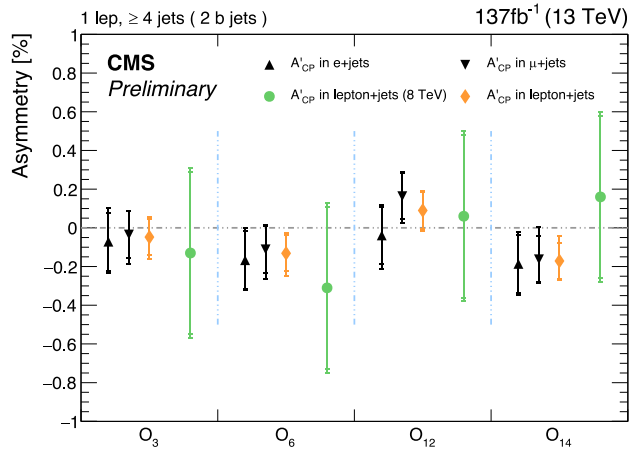


CMS-PAS-TOP-20-005



Raw asymmetries

NEW



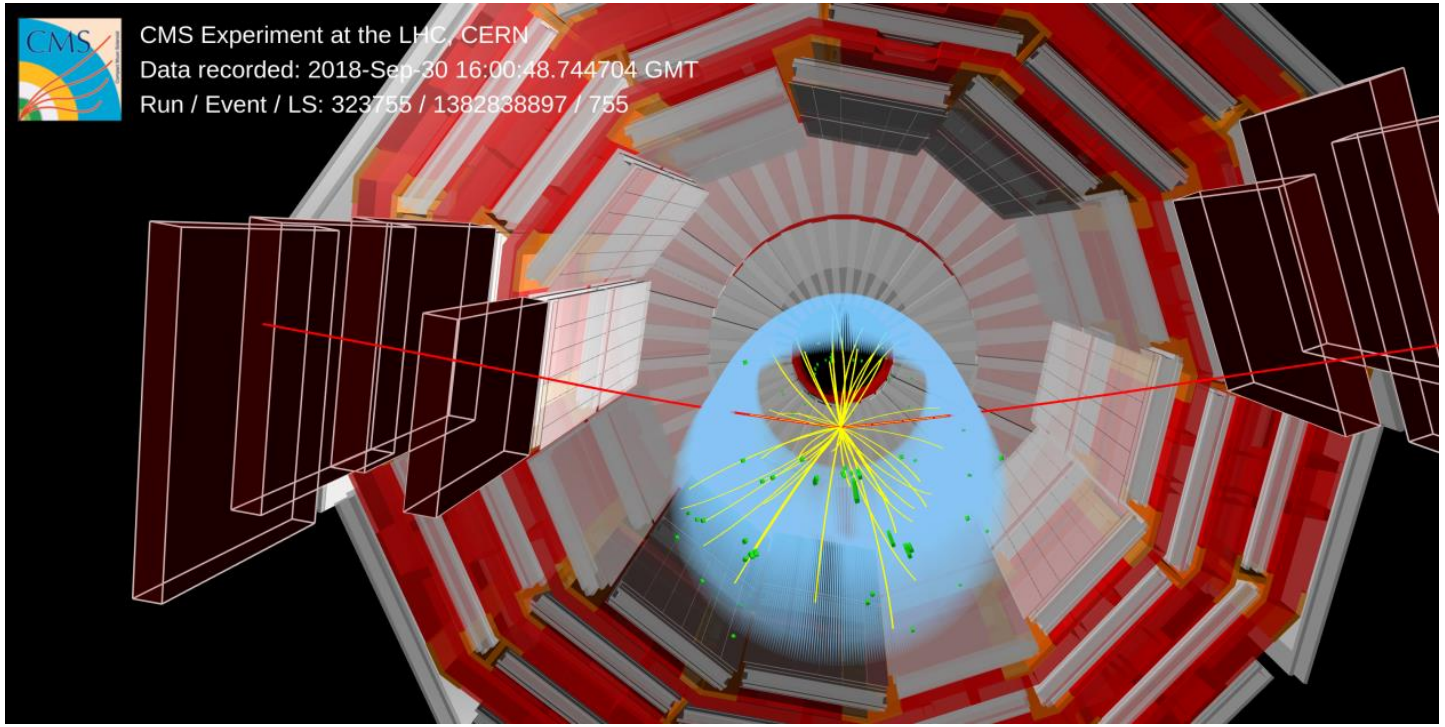
All measures asymmetries consistent with 0 indicating no CPV

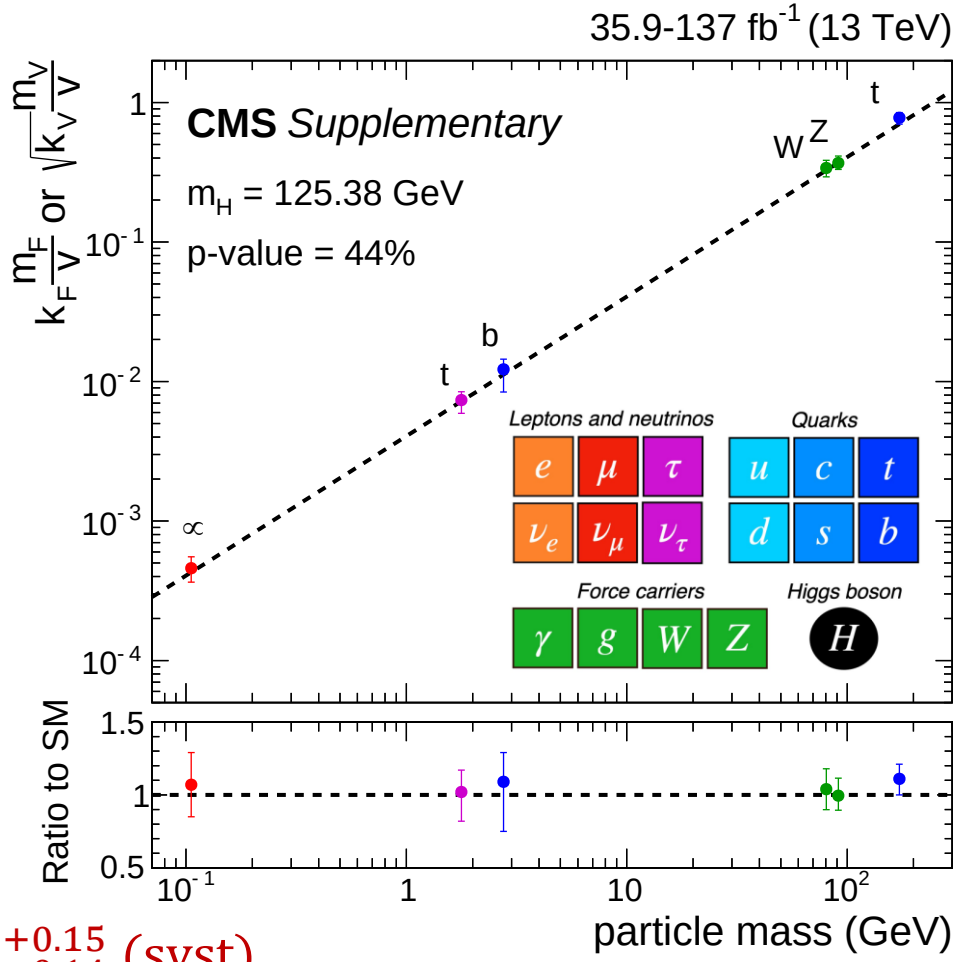
Talks of Reza Goldouzian (Thu) and Paolo Azzurri (Wed)

Evidence for H → μμ

- First evidence of the coupling of the Higgs boson with fermions of the second generation [JHEP 01 (2021) 148]

H → μμ candidate in gluon fusion channel
Mass = 125.46 ± 1.13 GeV



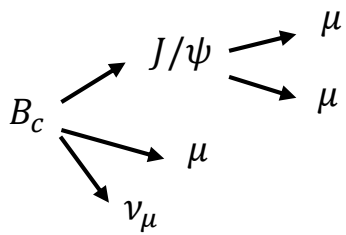


- Signal strength, relative to the SM prediction $\mu = 1.19^{+0.40}_{-0.39}\,(\text{stat})^{+0.15}_{-0.14}\,(\text{syst})$
- **Obs. (exp.) significance 3.0σ (2.5σ)**

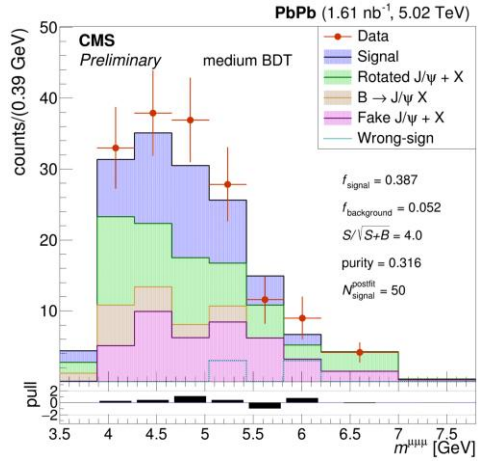
Talks of Silvio Donato (Mon) and Kerstin Tackmann (Tue)

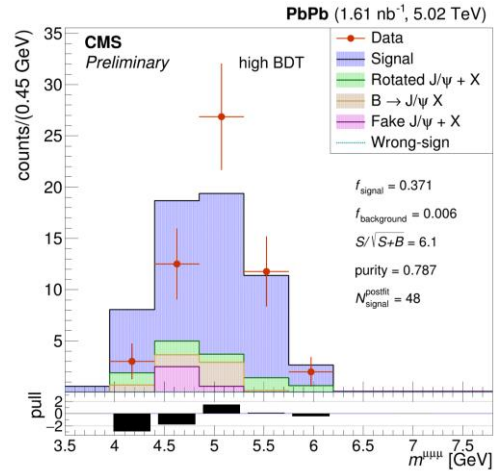
Heavy Ion results: first observation of B_c in PbPb

- B_c contains both b and c quark: bridge between bottom and charm mesons, and quarkonia
- Provides unique insight into the interplay between suppression and recombination (at low p_T)
- Signal is three displaced muons (2 OS making a J/ψ)



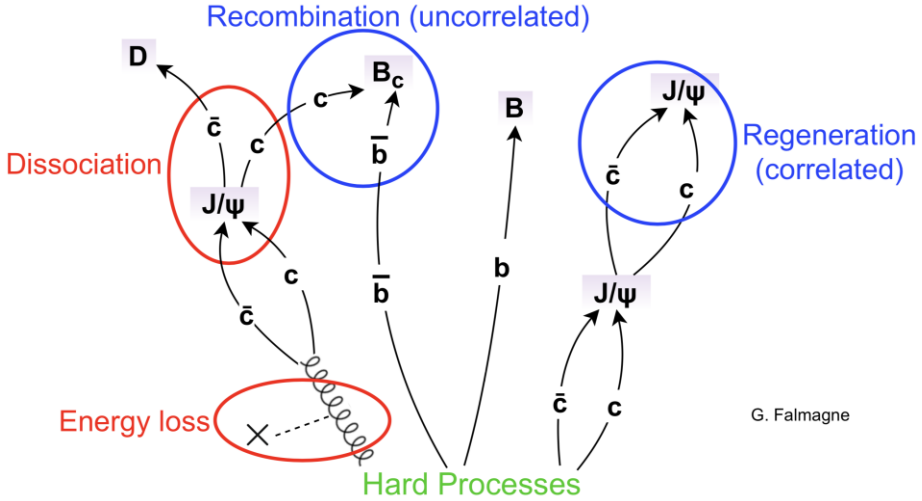
Medium and high BDT categories in the PbPb analysis

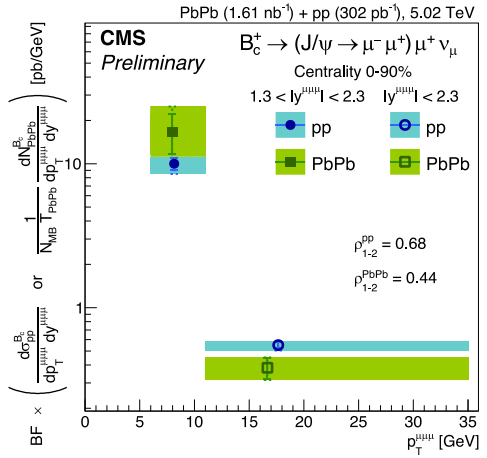


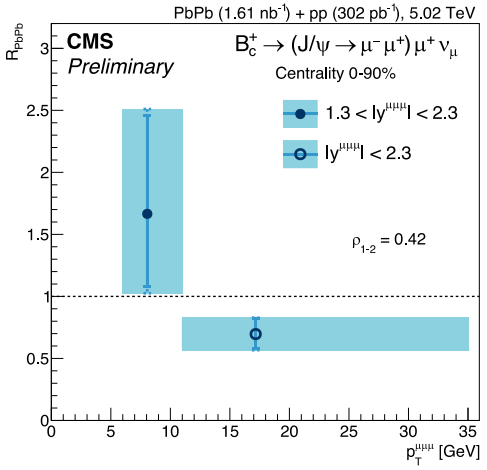


First observation of B_c in PbPb collisions, significance > 5σ

Interplay of several processes in B_c production



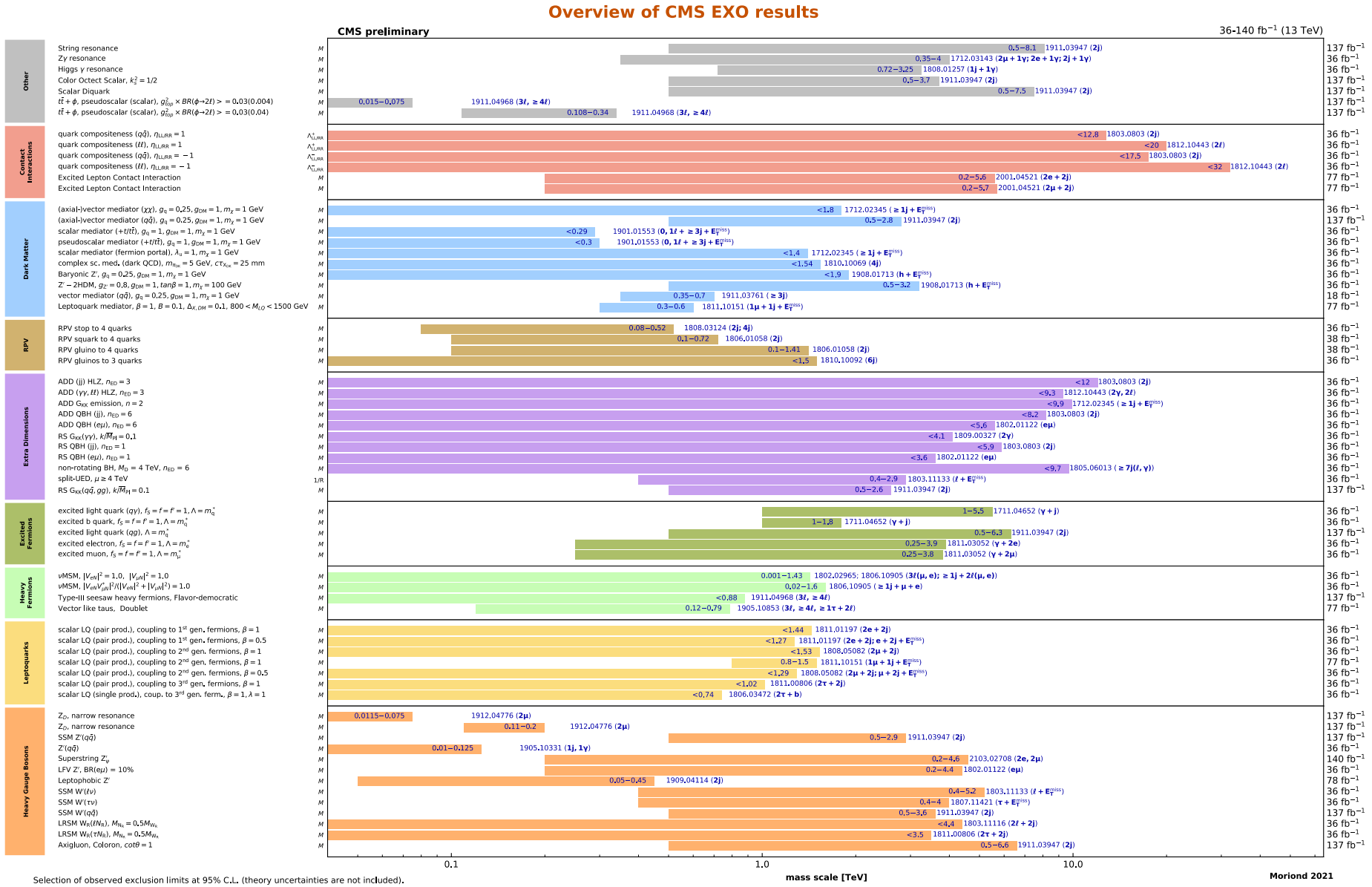




CMS-PAS-HIN-20-004

Hint of softened p_T spectrum in PbPb, 1.6σ difference between the two bins

Searches



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

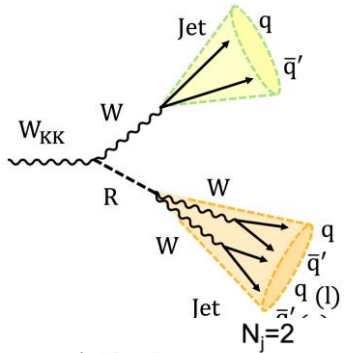
- Most standard searches have been carried out with Run 2 data
- Most analyses are now aimed at even more exotic signatures and models which have not yet been covered
- Also expanding searches for Long Lived Particles (LLP)

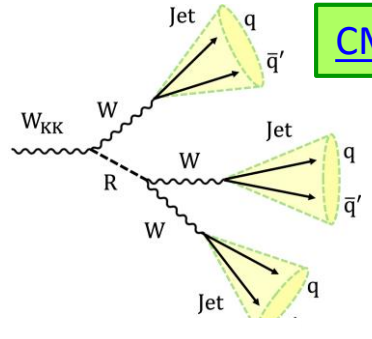
Search for resonances into three W bosons (hadronic decays)

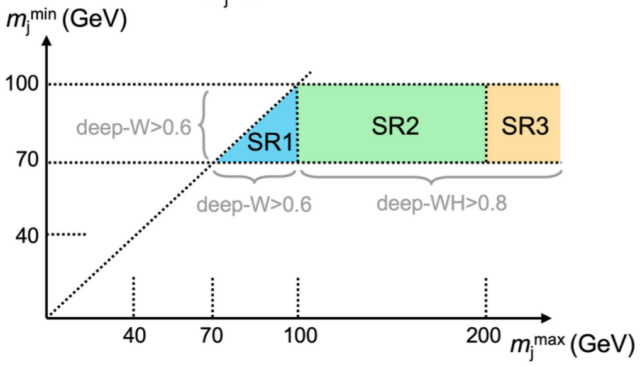
- Search for decays via a scalar radion R
  - X→WR→WWW,
- The radion can decay into 1 or 2 reconstructed large radius jets
- Results are combined with the complementary search in the l + jets finals state [CMS-PAS-B2G-20-001]

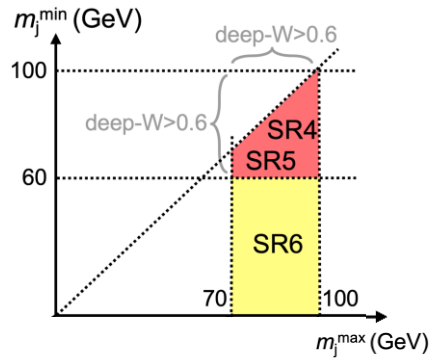
[CMS-PAS-B2G-21-002]

NEW

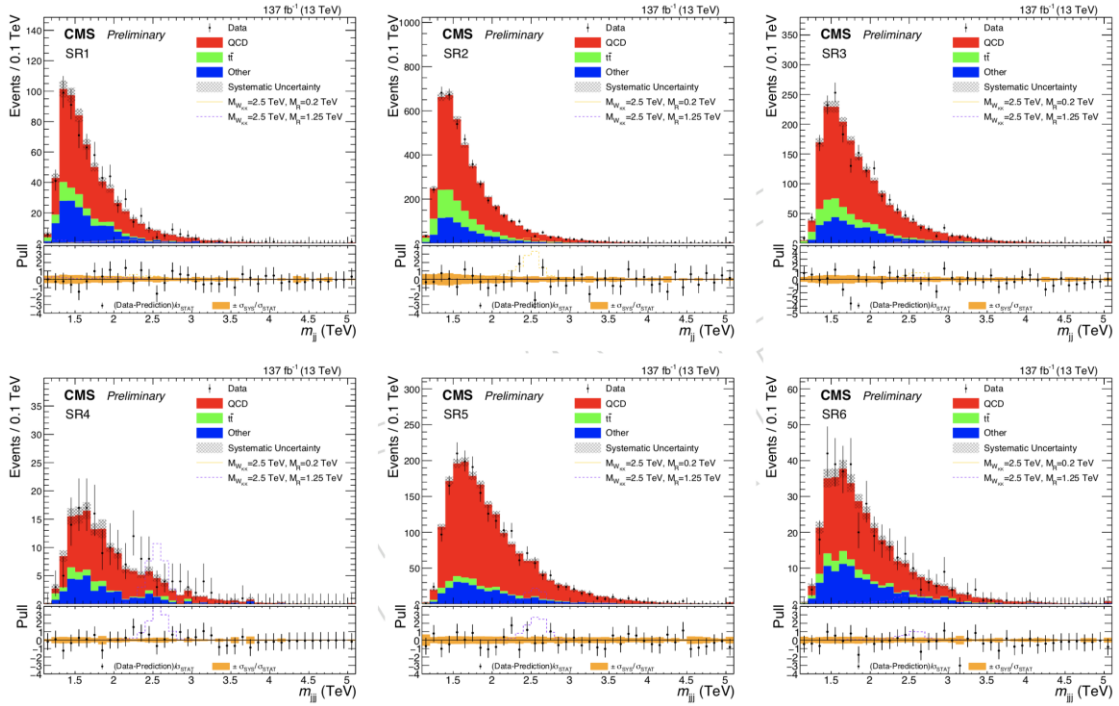


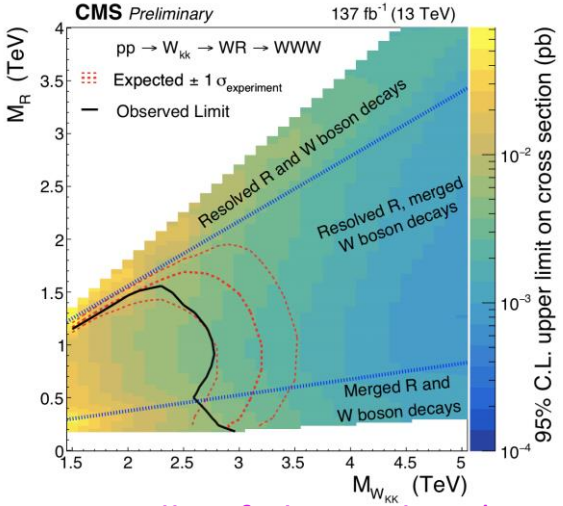


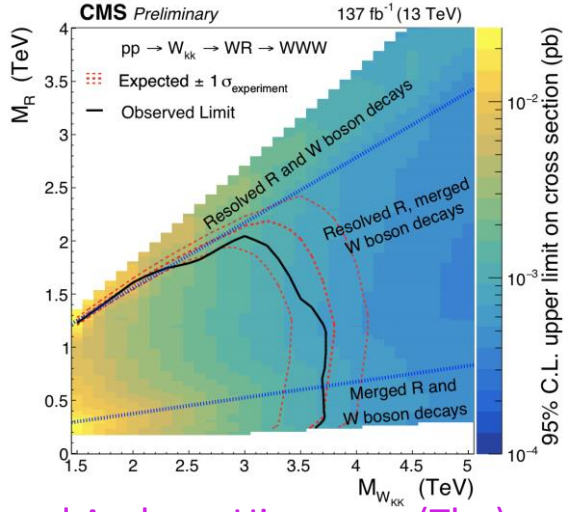




Resonance mass spectrum in the 6 categories







Talks of Cheng Chen (Mon) and Andreas Hinzmann (Thu)

Search for long lived Heavy Neutral Leptons

- Search for new HNL produced with mixing with SM neutrinos, final states with three charged leptons and a neutrino
- For small values of the HNL mass (<20 GeV) and of the HNL-SM neutrino mixing parameter HNL may be long lived

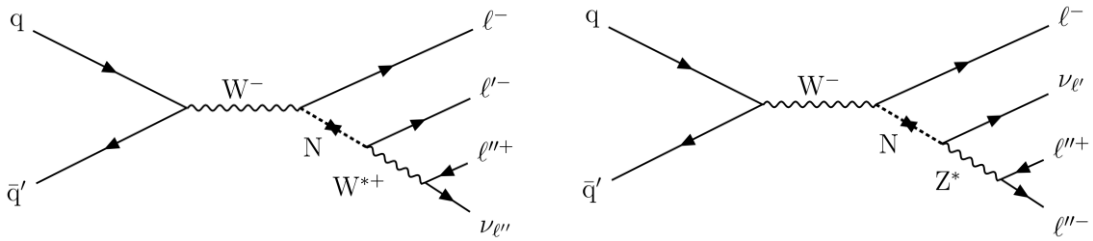
$$\tau_N \propto m_N^{-5} V_{Nl}^{-2}$$

- Search for three lepton events (e and μ) with two forming a displaced vertex and the third prompt

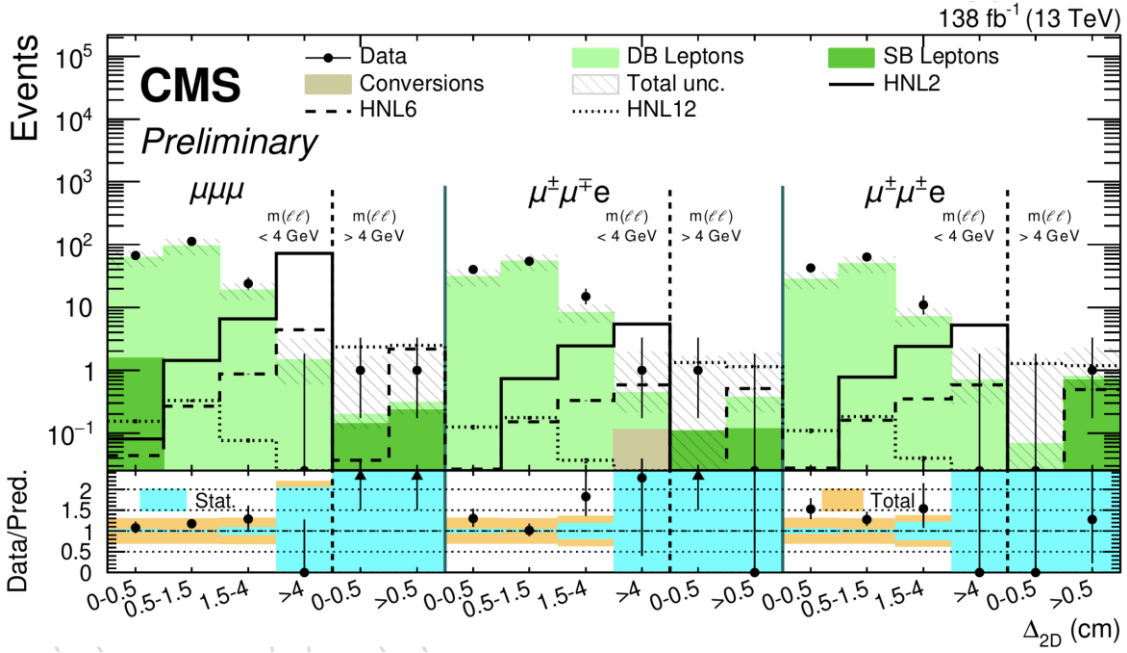
CMS-PAS-EXO-20-009

NEW

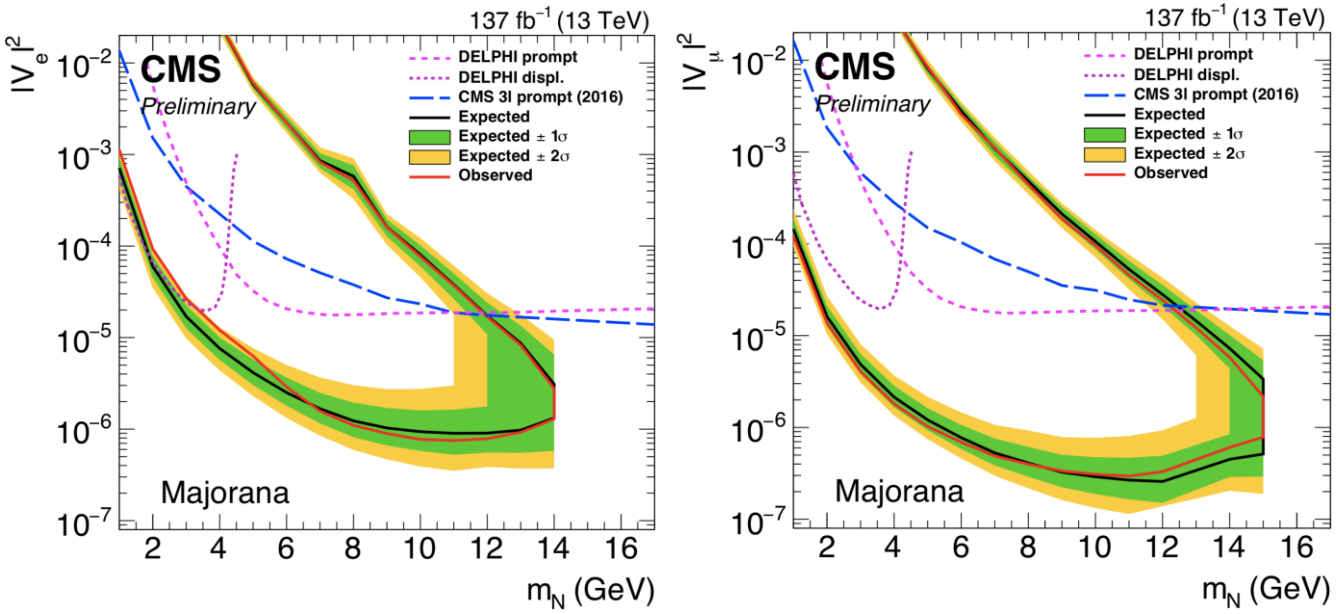
Several diagrams with LFV (Majorana N) and LFC (Majorana or Dirac N) are possible



2D displacement of the dilepton vertex for events With 2 muons in the different categories



2D exclusions in the plane mixing vs N mass

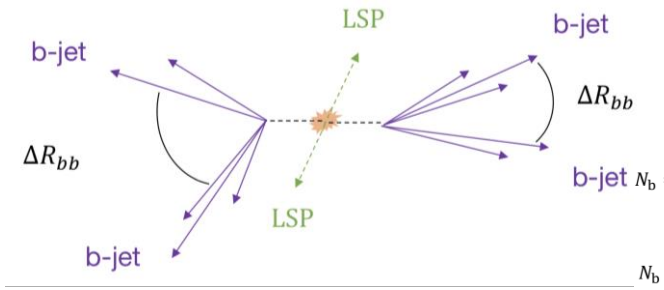


Talks of Bryan Cardwell (Tue) and Andreas Hinzmann (Thu)

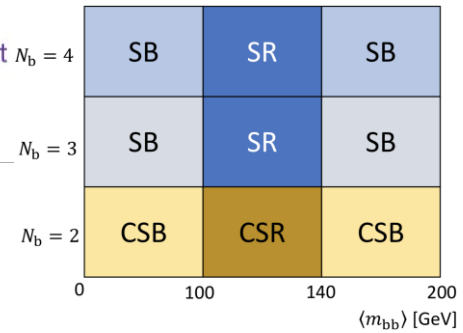
Search for SUSY in HH(4b)+MET final states

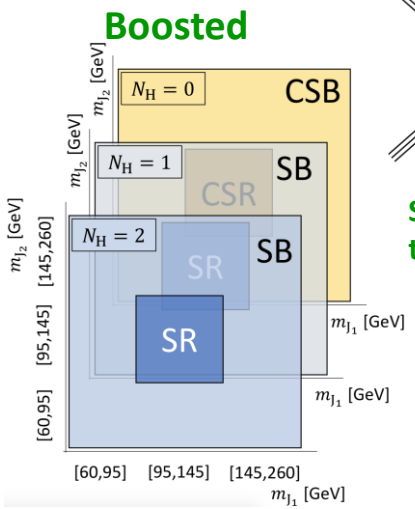
- Search carried out for boosted ($\Delta R_{bb} < 0.8$) and resolved ($\Delta R_{bb} > 0.4$) Higgs to bb (exclusive search enforced by giving priority to the resolved search)
- Search results are interpreted using simplified SUSY models

CMS-PAS-SUS-20-004



Event categories:

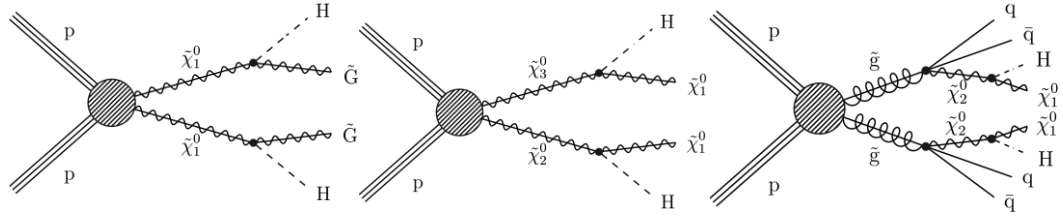




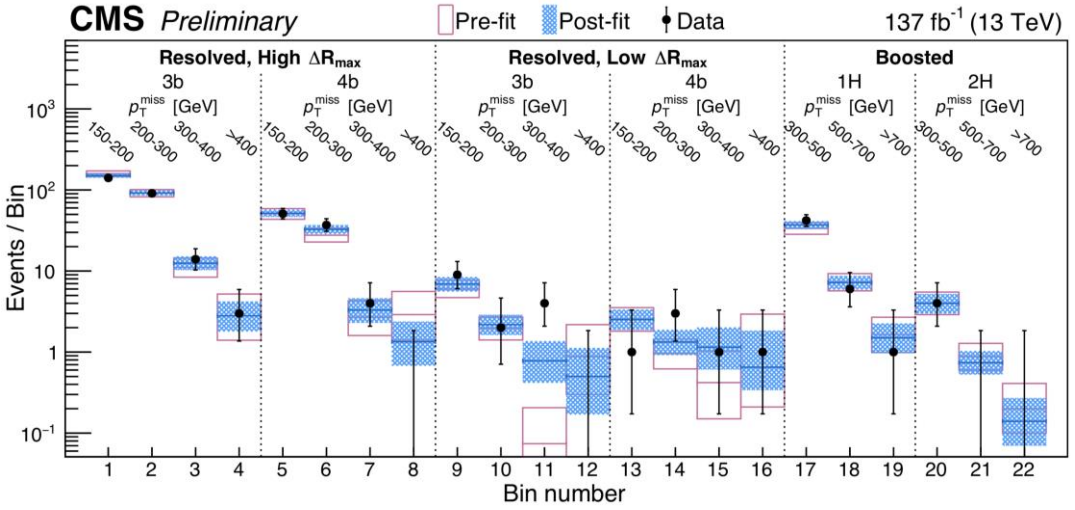
TChiHH-G GMSB model

TChiHH model

T5HH model



Several intermediate gluinos, charginos and neutralinos may contribute to the final state

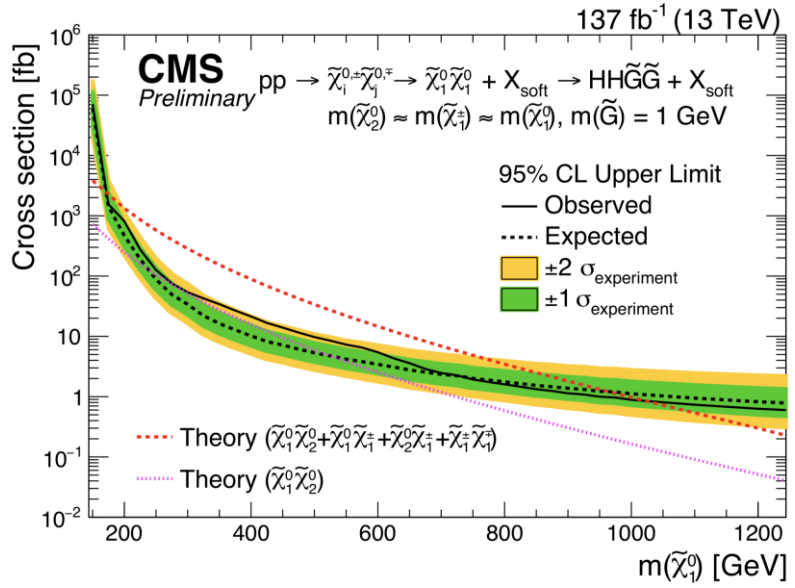


Small excess in one single bin (1.9σ global)

Excluded at 95%C.L.:

- TChiHH-G:
  $175 < m_{\tilde{\chi}_1^0} < 1025$ GeV
- T5HH:
  $m_{\tilde{g}} < 2330$ GeV

Exclusion limit in the GMSB model

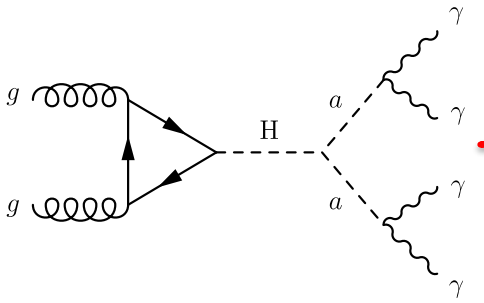


Talks of Liam Wezenbeek (Mon) and Andreas Hinzmann (Thu)

Search for $h \to aa \to \gamma\gamma\gamma\gamma$

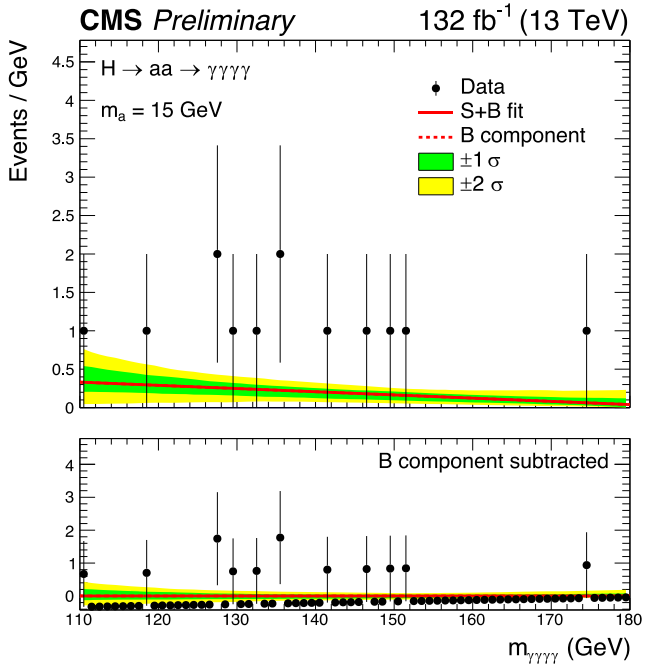
- Search for 4 isolated photons in the mass range $15 < m_a < 60$ GeV
- A BDT classifier parametrized as function of the hypothesized pseudoscalar mass $m_{a(hyp)}$ is trained and used to optimize the selection
- h(125) mass peak signal plus smooth background fitted to data

CMS-PAS-HIG-21-003

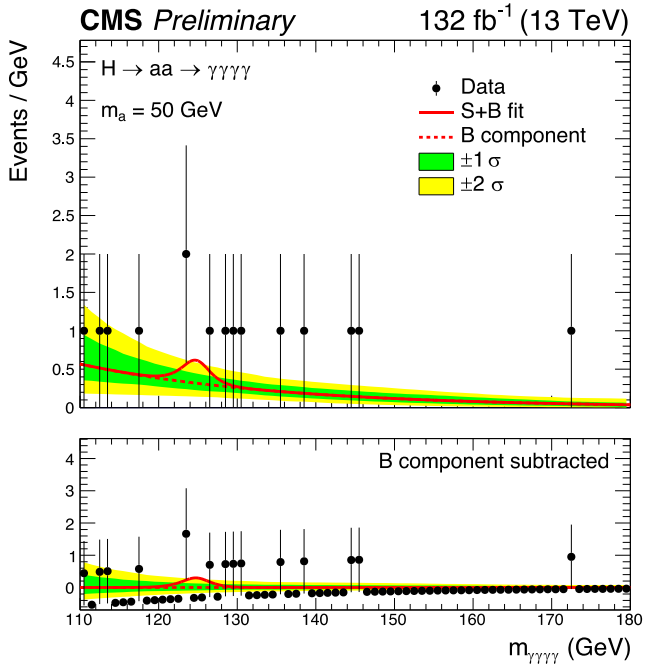


NEW

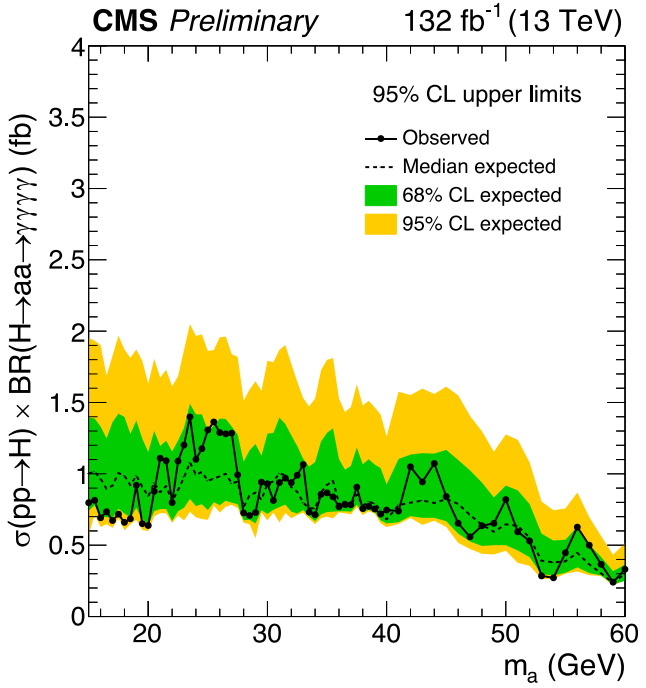
$m_{a(hyp)}$= 15 GeV



$m_{a(hyp)}$= 50 GeV



No excess seen and limits derived



Talks of Antoine Lesauvage (Mon)

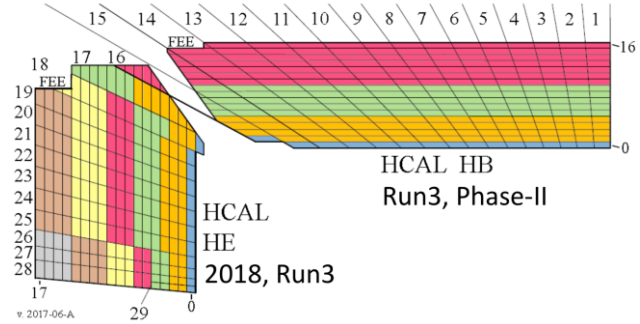
Long Shutdown 2 and Run 3 preparation

Long Shutdown 2 (LS2)

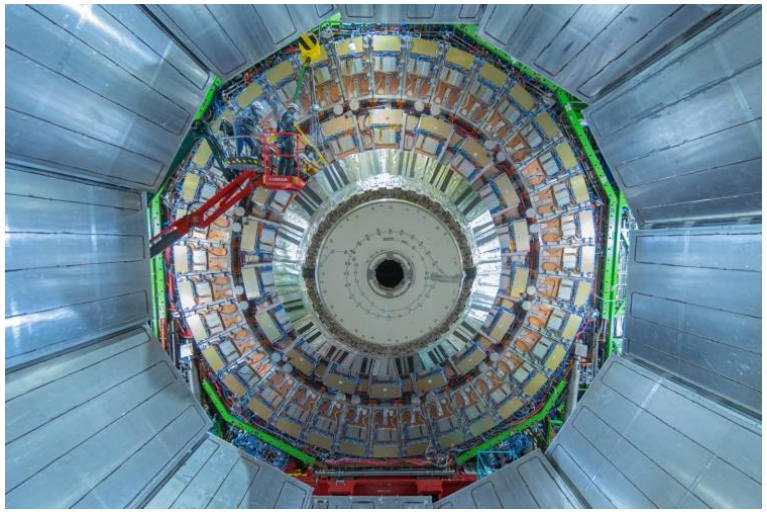
- Run 2 ended in 2018 and Run 3 will take place from 2022 to 2024 at CM energy between 13 and 14 TeV
  - Pilot Beam Test Oct. 21, start of Run-3 2022 (stable beams expected in May)
  - expected to more than double the integrated luminosity of Run 2
- 2019-2021, long shutdown between Run and Run 3 (LS2)

Highlights of activities during LS2
Mostly done, detector ready to close

HCAL readout upgrade

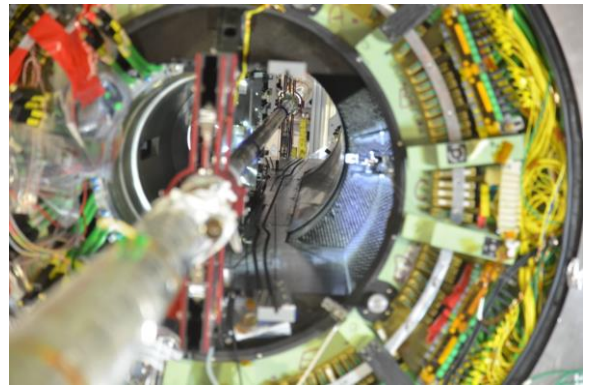


GEM detector first station (GE1/1) (first Phase II upgrade) installed during the COVID pandemic



New beam pipe installed

New Barrel Pixel layer 1 installed



- **Cosmic Running started 2 weeks ago with the complete detector to get ready for the Pilot Test beam in October**

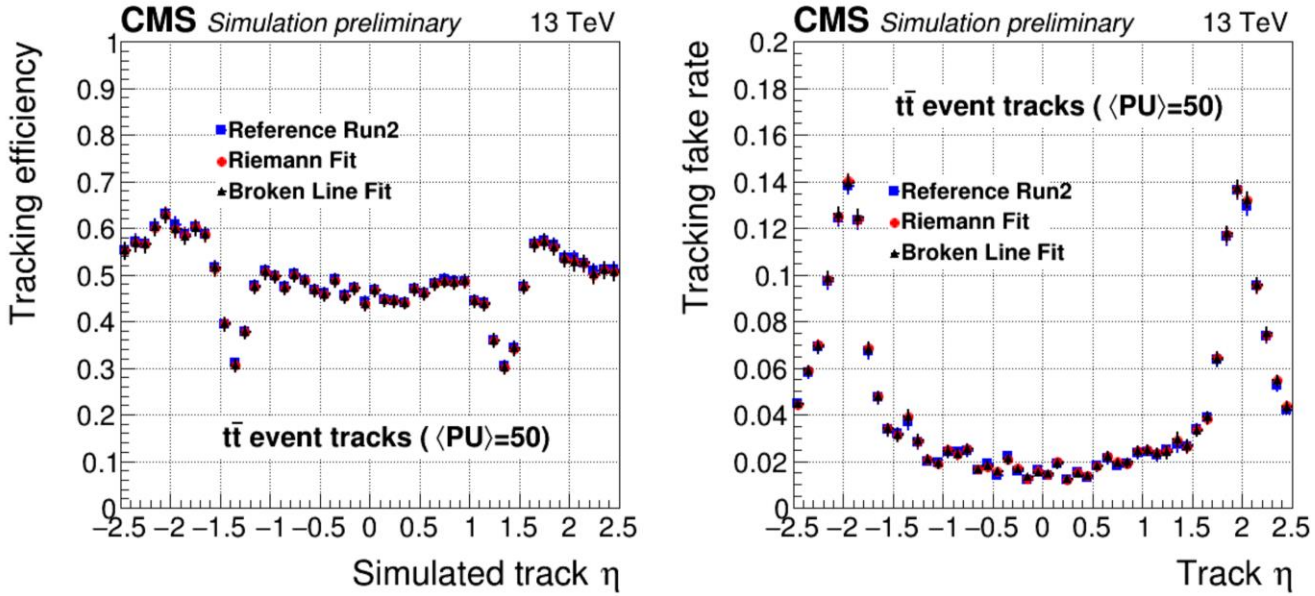
Run 3 opportunities for Physics

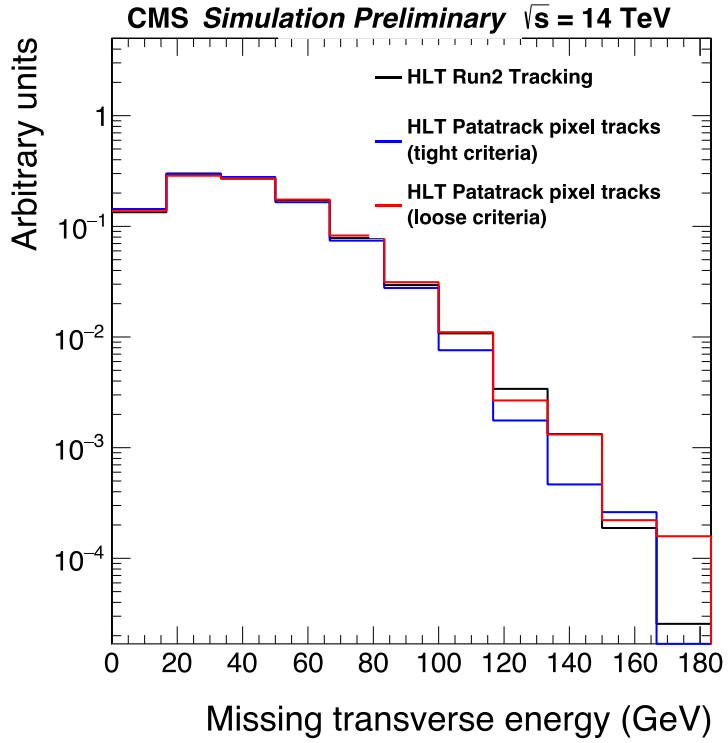
- All analyses will be repeated with up to twice the integrated luminosity
  - Additional improvements in sensitivity from further developments, including ML techniques, and reduction of the systematic uncertainties
- Furthermore, we will further improve trigger and non-conventional data taking methods (Data Scouting and (B-)parking)
- Special attention to Long lived particle searches

Developed heterogeneous event reconstruction at HLT (CPU + GPU)

- Already offload ~30% of reconstruction to GPUs:
- ECAL & HCAL local reconstruction, pixel reconstruction and tracking.
  - **Important gains in performance at HLT** (including scouting)
  - **Current baseline for Run 3** HLT farm

Pixel track reconstruction on GPU in tt events

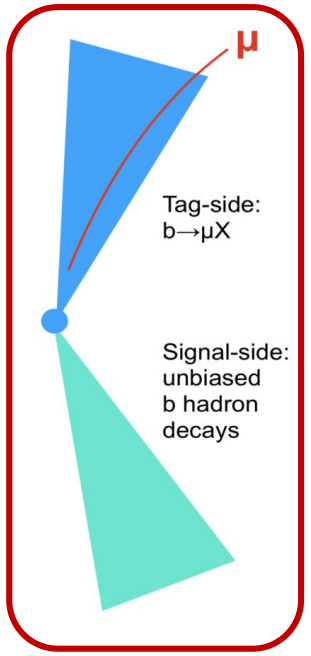




MET Reconstructed With Particle Flow Based on pixel tracks

Developments in view of Run 3

- B-parking
  - in 2018 we used low p_T displaced triggers to save a sample of unbiased B hadron decays recoiling wrt the triggered muon
    - Parked trigger rate ~2kHz was reconstructed after the end of the run
  - **Enables several analyses on LFU violation** currently in progress
    - Expect first approved results soon
  - **Studying how to further optimize the trigger in Run 3**
- Scouting
  - Analysis based on a reduced data format and on the online reconstruction in the HLT farm (do not save the full event data)
  - In Run 2 all analyses based about 5 kHz (~1 kHz of Particle Flow scouting)
  - **For Run 3 aim at running PF on higher rate, possible adding additional L1 triggers (use GPUs and pixel tracks)**
- LLP improvements
  - **Ongoing developments in the L1 trigger** area with the aim to increase efficiency for displaced signatures
    - Increase efficiency for displaced muons
    - Extend muon triggers to hadronic showers
    - Out of time ECAL and HCAL at L1
    - Using HCAL depth information
  - **HLT developments also ongoing**

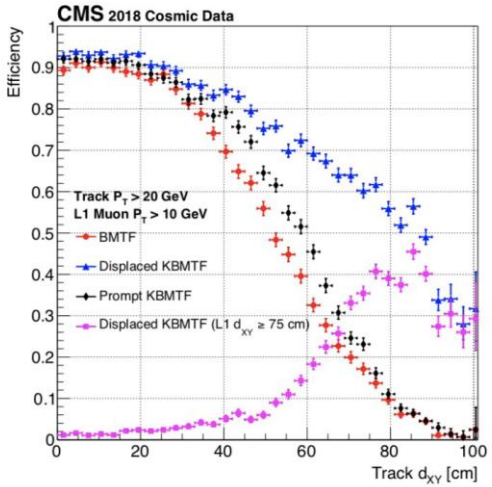


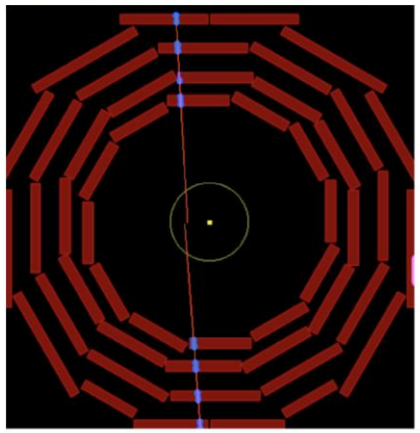
Collected billions of unbiased B decays
12 billion events total

Mode	N_{2018}	f_B	$\mathcal{B}$
Generic b hadrons			
B_d^0	4.0×10^9	0.4	1.0
$B^\pm$	4.0×10^9	0.4	1.0
B_s	1.2×10^9	0.1	1.0
b baryons	1.2×10^9	0.1	1.0
B_c	1.0×10^7	0.001	1.0
Total	1.0×10^{10}	1.0	1.0
Events for R_K and R_{K^*} analyses			
$B^0 \to K^* \ell^+ \ell^-$	2600	0.4	6.6×10^{-7}
$B^\pm \to K^\pm \ell^+ \ell^-$	1800	0.4	4.5×10^{-7}

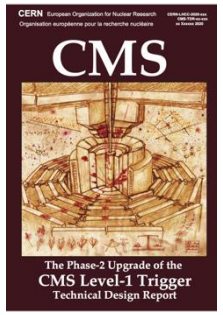
Kalman filter at L1

tested in parallel in 2018 and commissioned with cosmic rays





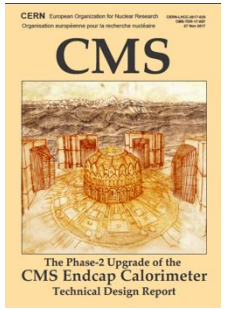
CMS Phase II Upgrades for HL-LHC



L1-Trigger HLT/DAQ

https://cds.cern.ch/record/2714892
https://cds.cern.ch/record/2283193

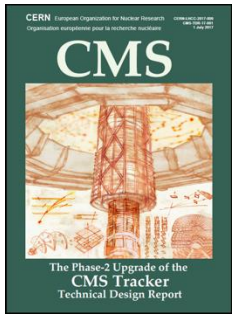
- Tracks in L1-Trigger at 40 MHz
- PFlow selection 750 kHz L1 output
- HLT output 7.5 kHz
- 40 MHz data scouting



Calorimeter Endcap

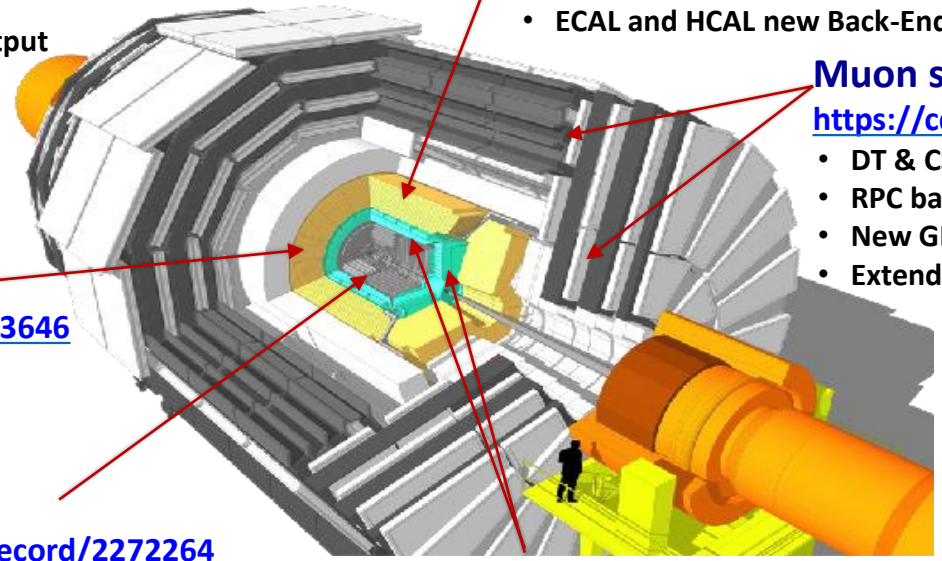
https://cds.cern.ch/record/2293646

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS



Tracker https://cds.cern.ch/record/2272264

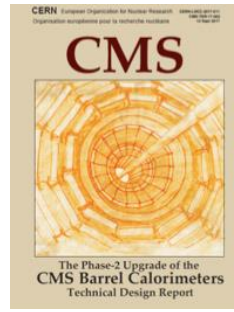
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to η ≃ 3.8



Barrel Calorimeters

https://cds.cern.ch/record/2283187

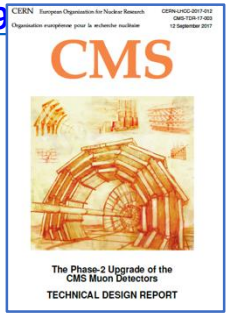
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Muon systems

https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η ≃ 3

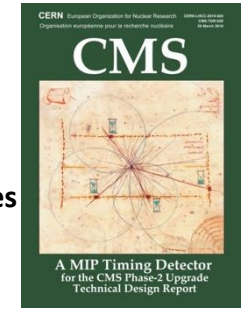


MIP Timing Detector

https://cds.cern.ch/record/2667167

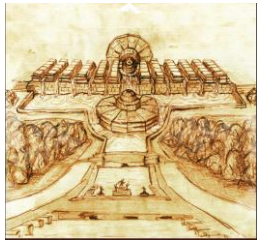
Precision timing with:

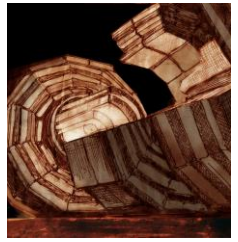
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes



All shown Technical Design Reports approved by the LHC Committee.
Two currently under scrutiny:

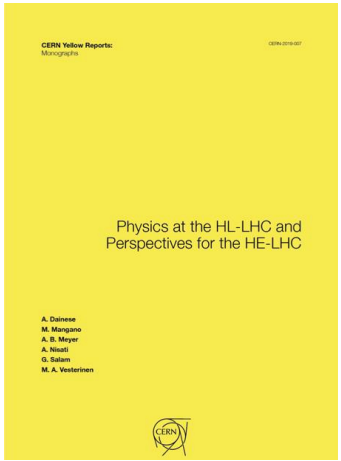
DAQ/HLT **BRIL**



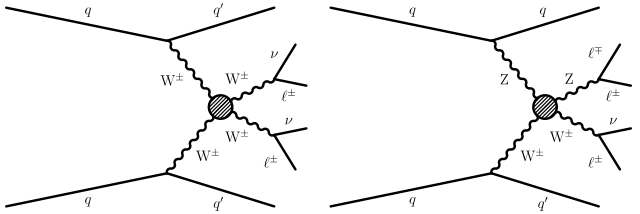


Physics studies for HL-LHC

- The 2019 Yellow report gives a comprehensive review of the physics at the HL-LHC:
  - https://cds.cern.ch/record/2703572?ln=en
- More studies starting to appear the context of the Snowmass activities
- First CMS public results here:



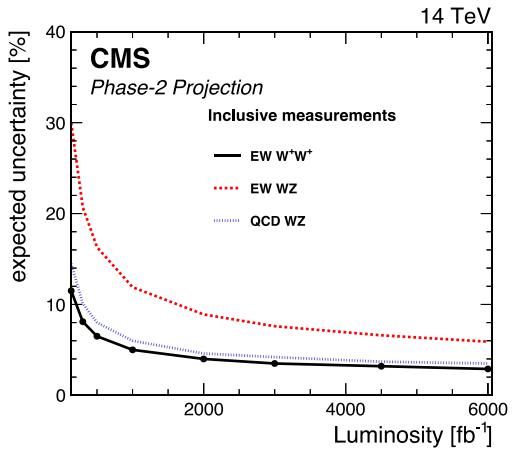
- **VBS measurement of $W^{\pm}W^{\pm}$ and WZ at HL-LHC uses leptonic decay modes of both W and Z where l = e, μ**
  - Extrapolated from full Run 2 analysis
  - Contributions of $W_L^{\pm}W_L^{\pm}$, $W_L^{\pm}W_T^{\pm}$ and $W_T^{\pm}W_T^{\pm}$ are measured in the $W^{\pm}W^{\pm}$ CM reference frame or in the initial-state parton-parton one



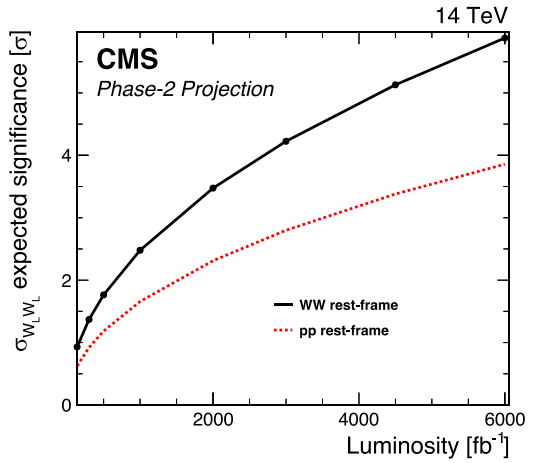
Mode	WW reference frame fraction (%)	Parton-parton reference frame fraction (%)
$W_L^{\pm}W_L^{\pm}$	10.9	7.3
$W_L^{\pm}W_T^{\pm}$	31.9	37.4
$W_T^{\pm}W_T^{\pm}$	57.2	55.3

[CMS-PAS-FTR-21-001]

Uncertainty for inclusive measurements



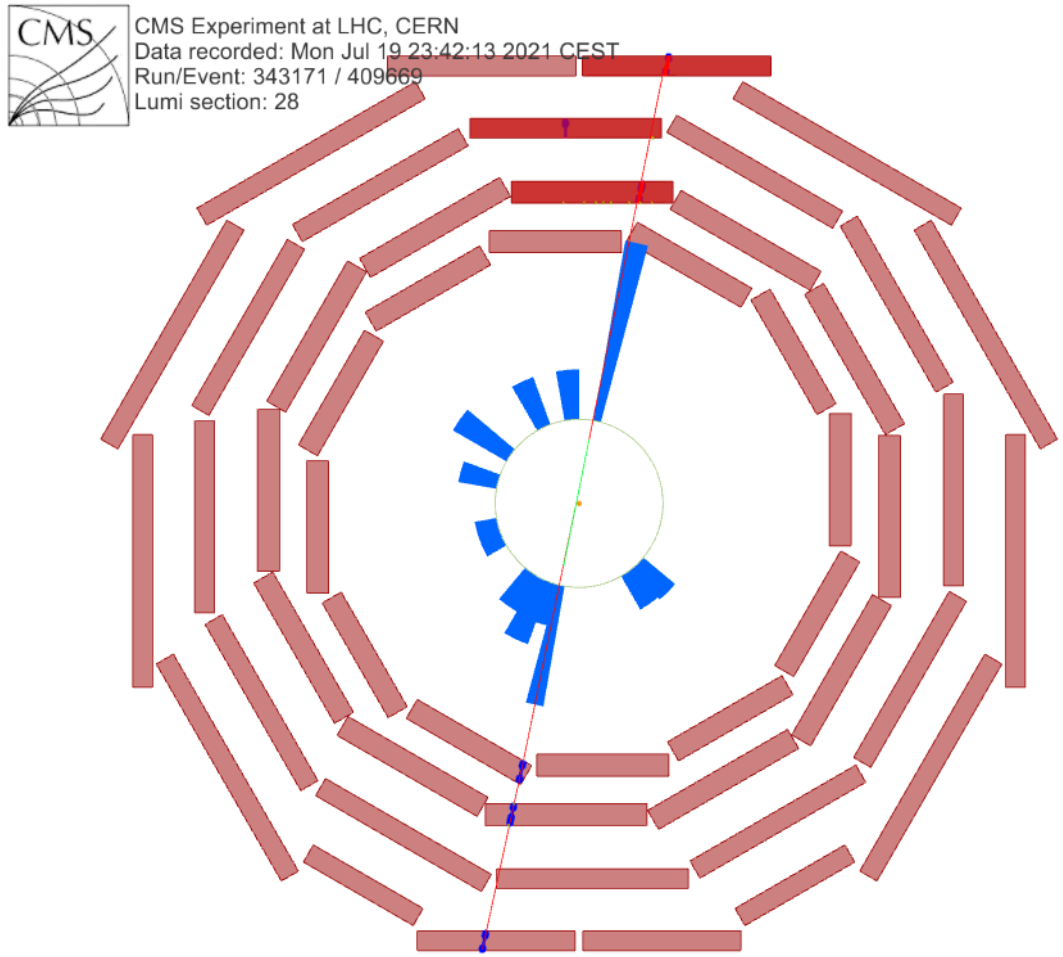
Expected significance for the detection of W_LW_L



Summary

- **26 new analyses made public for EPS**
  - All Physics Analysis Summaries at the links indicated and will appear shortly at: http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/CMS/index.html
  - Physics Briefings at: https://cms.cern/tags/physics-briefing
- Run 3 preparation ongoing
  - LS2 work mostly complete
  - Detector almost ready to be closed to cool down and commission the magnet by October
  - **Currently taking cosmic data for alignment**
  - **Many new developments ongoing for a successful Run 3**
- Phase 2 upgrades and High Luminosity LHC
  - All Technical Design Reports prepared, last two under review
  - More physics projections for HL-LHC starting to appear

CRUZET Cosmic RUn at ZEro Tesla for detector alignment July/August 2021



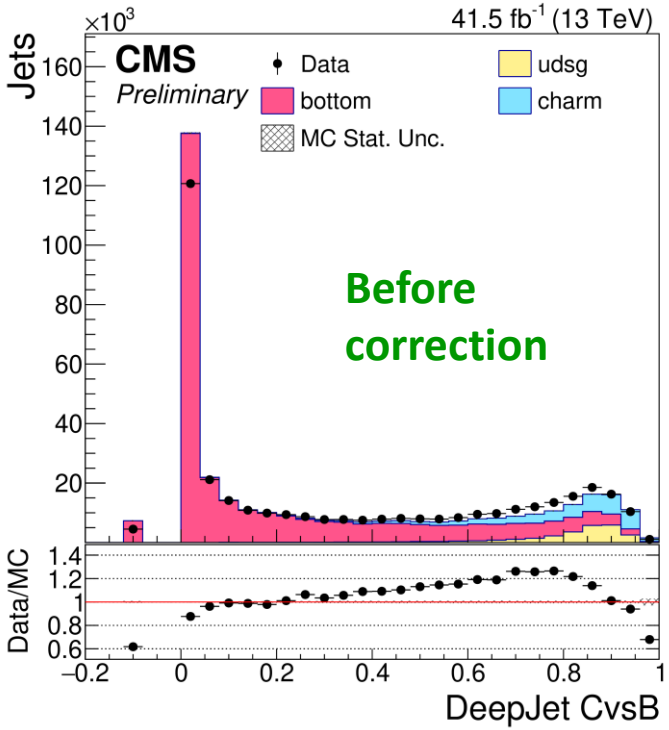
Backup

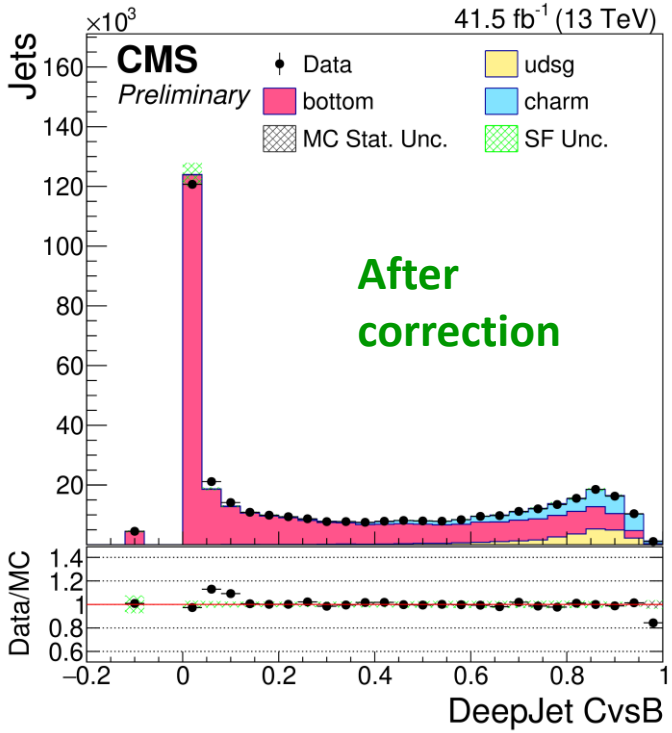
Calibration of charm jet identification algorithms

- Calibration method to correct the differential C-vs-B and C-vs-L discriminator shapes for two main HF tagging algorithms: DeepCSV and DeepJet
  - DeepCSV: DNN with higher level variables as input (simpler)
  - DeepJet: : DNN with lower level variables as input (more complex)

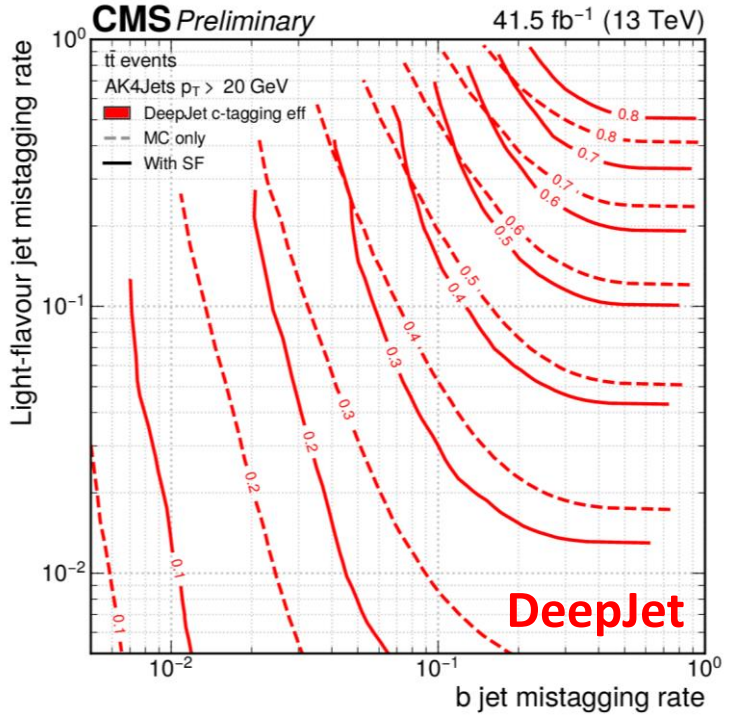
CMS-PAS-BTV-20-001

- Iterative fit procedure that exploits control regions enriched in b (tt), c (W+c) and gluon/light-flavour jets (DY+jet) respectively





c-tag performance

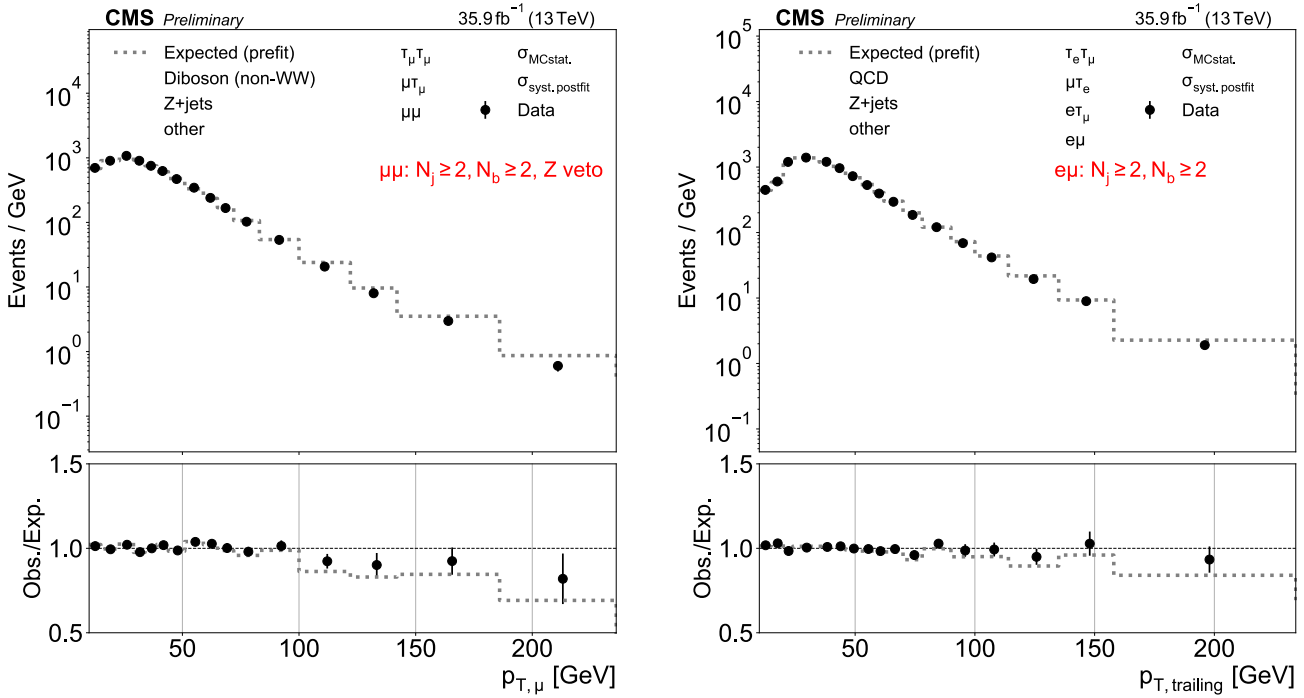


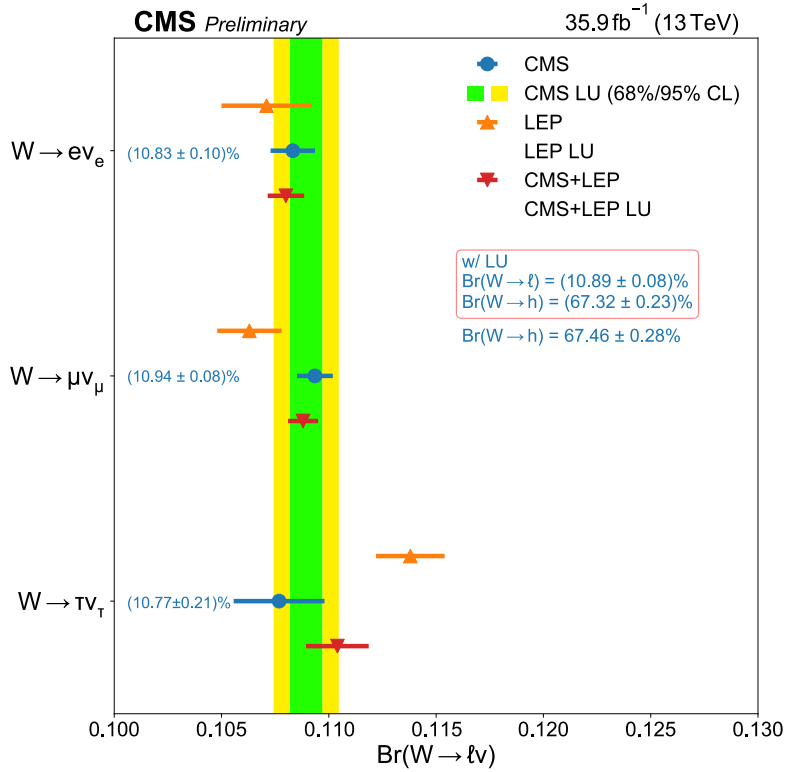
Measurement of W Branching Fractions

- Events with two W or a W + jets (mostly from tt production) are used to measure BR of W with 2016 data
- Exploit pT as a way to distinguish prompt muons from muonic decays of taus
- Precision slightly better than LEP

CMS-PAS-SMP-18-011

	CMS	LEP
$\mathcal{B}(W \to e\overline{\nu}_e)$	$(10.83 \pm 0.01 \pm 0.10)\%$	$(10.71 \pm 0.14 \pm 0.07)\ \%$
$\mathcal{B}(W \to \mu\overline{\nu}_\mu)$	$(10.94 \pm 0.01 \pm 0.08)\%$	$(10.63 \pm 0.13 \pm 0.07)\ \%$
$\mathcal{B}(W \to \tau\overline{\nu}_\tau)$	$(10.77 \pm 0.05 \pm 0.21)\%$	$(11.38 \pm 0.17 \pm 0.11)\ \%$
$\mathcal{B}(W \to h)$	$(67.46 \pm 0.04 \pm 0.28)\%$	–
with LU		
$\mathcal{B}(W \to \ell\overline{\nu})$	$(10.89 \pm 0.01 \pm 0.08)\%$	$(10.86 \pm 0.06 \pm 0.09)\%$
$\mathcal{B}(W \to h)$	$(67.32 \pm 0.02 \pm 0.23)\%$	$(67.41 \pm 0.18 \pm 0.20)\%$

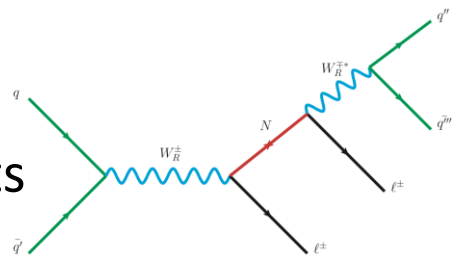




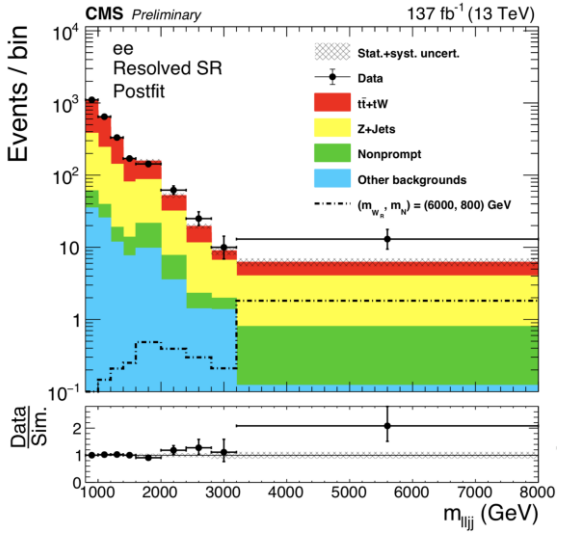
Search for W_R decaying to HNL

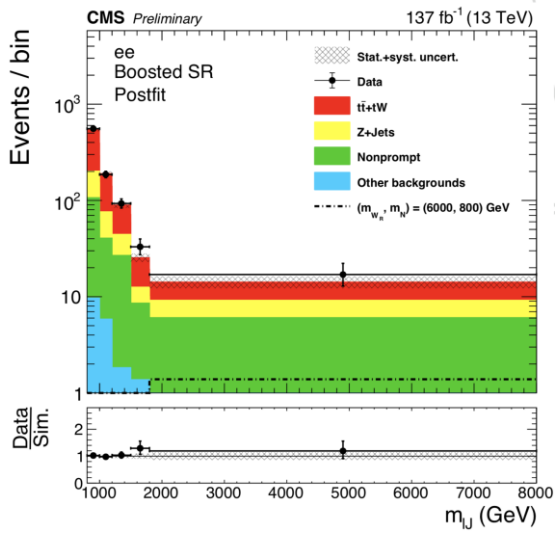
- Search for new charged boson (W_R) and heavy right-handed neutrino (N) under the LR symmetric model
- Analysis carried out with ee and μμ and merged and resolved jets

CMS-PAS-EXO-20-002

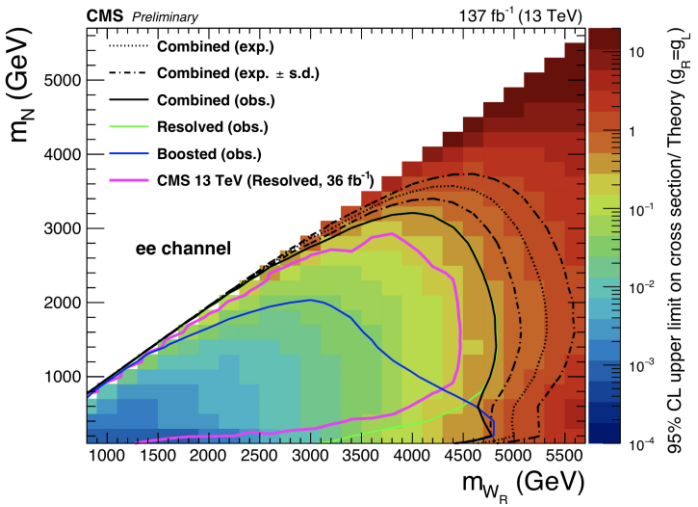


NEW

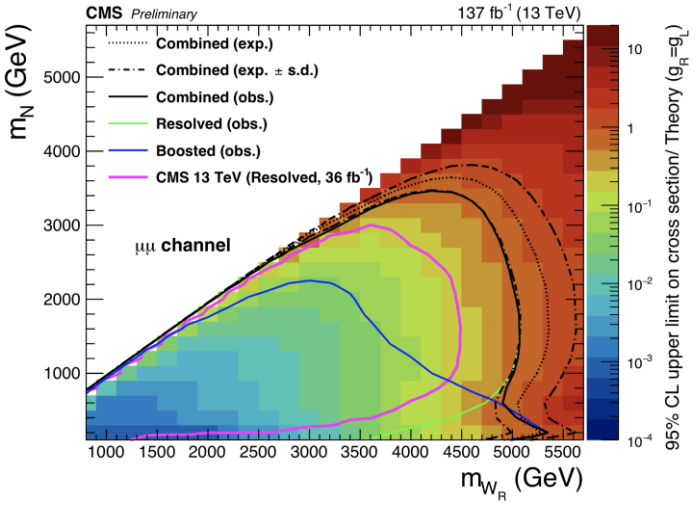




ee



μμ

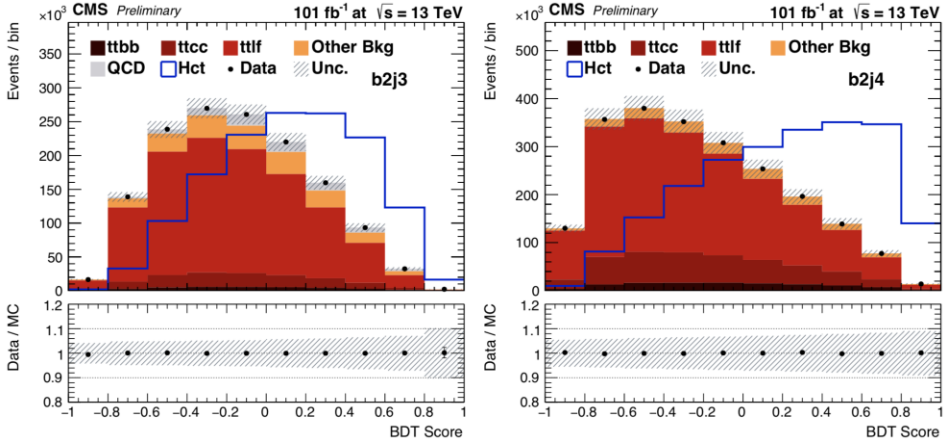


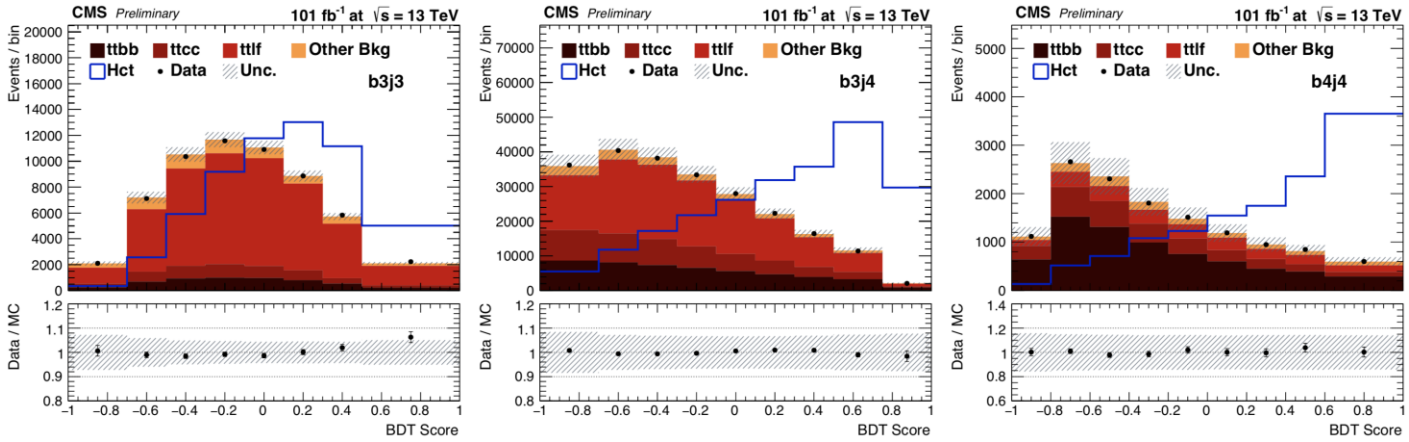
- For $m_N = 0.5\ m_{WR}$ (m_N = 200 GeV), the mass of the W_R is excluded at 95% CL up to 4.7 (4.8) and 5.0 (5.4) TeV for the ee and $\mu\mu$ channel
- Most stringent limits on the W_R mass to date
- Some excess in the high mass bin of the electron channel, max local significance 2.95 σ (2.78 σ global) for (m_{WR}, m_N) = (6000, 800) GeV

FCNC in top quark and Higgs boson interactions ($H \rightarrow bb$)

- Search for events with 1 e or μ and at least 3 jets (at least two b-tagged)
- DNN used to associate the reconstructed objects to the matrix-element partonic final state

2017+2018 data in the 5 categories defined based on jet/b-tag multiplicity (2016 data combined from publication)



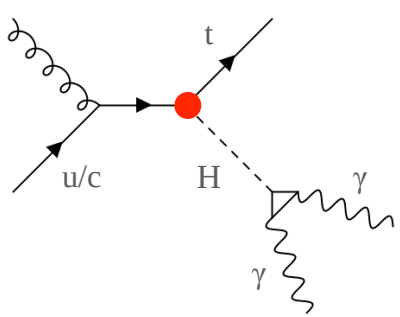


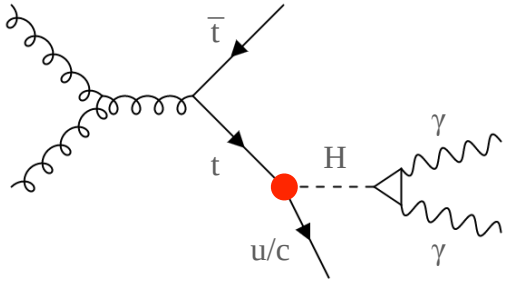
CMS-PAS-TOP-20-007

Previous analysis with $H \rightarrow \gamma\gamma$

Observed (expected) 95% CL upper limits on

- B(t → Hu) < 0.019% (0.031%)
- B(t → Hc) < 0.073% (0.051%)





- B(t → Hu) < 0.08% (0.11%)
- B(t → Hc) < 0.09% (0.09%) at 95% C.L. (assuming one non-zero coupling only)

CMS-PAS-TOP-19-002

NEW

Search for heavy resonances decaying to b quarks

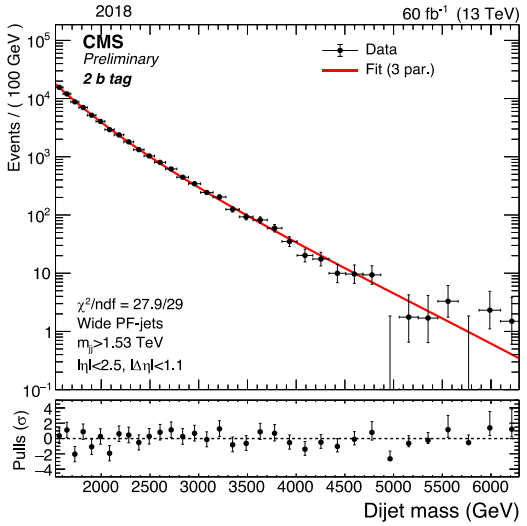
- Resonances decaying into 1 or 2 b-quarks (e.g. Z' or b*)

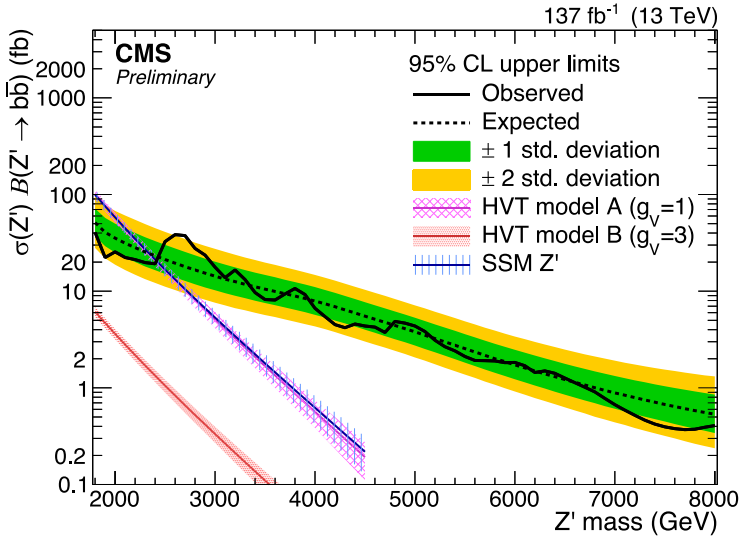
CMS-PAS-EXO-20-008

  - SSM has a Z' with same couplings as the Z but with larger mass and is generalized in the HVT framework with different couplings to fermions and bosons
  - Three categories used for the Z' search (2b, 1b and μ), and 1 for the b* search ($\geq 1b$)

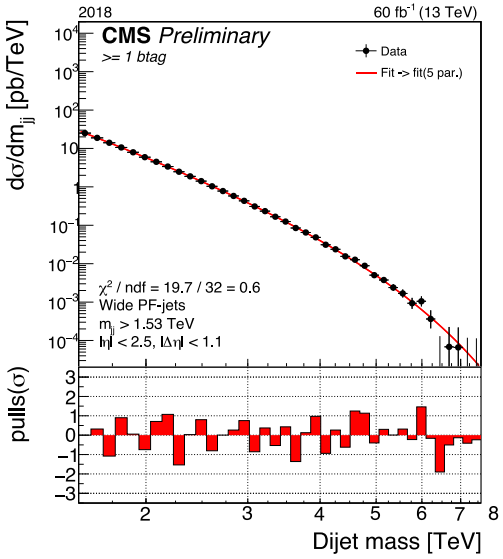
NEW

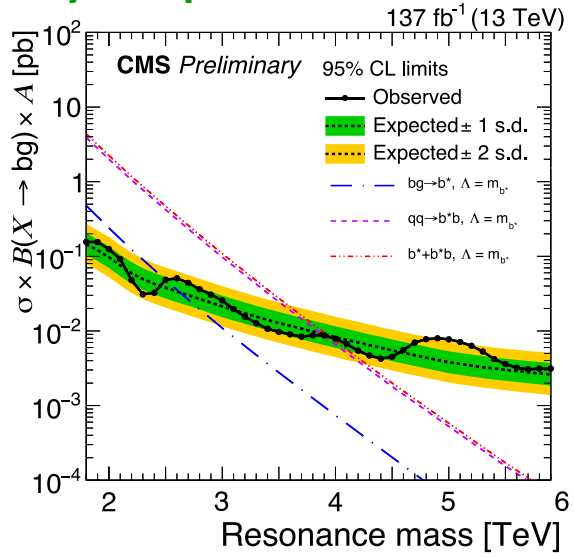
Z' analysis and limits





Expected cross section times A
Dominated by b*b production





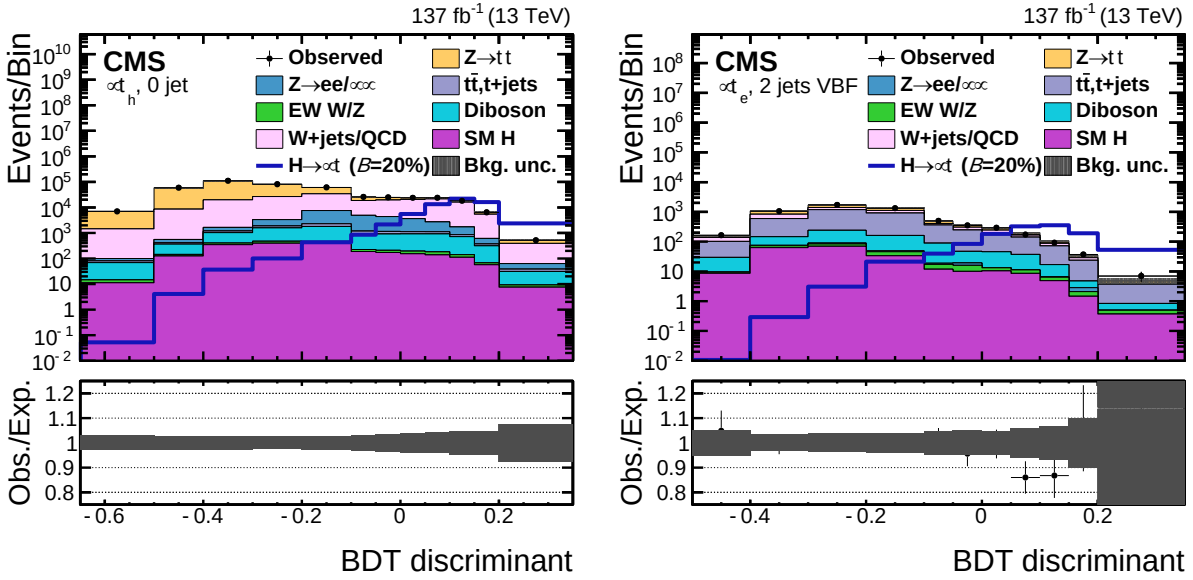
Z' bosons in SSM and HVT model A are excluded at 95% C.L. with a mass less than 2.4 TeV (2.3 expected)

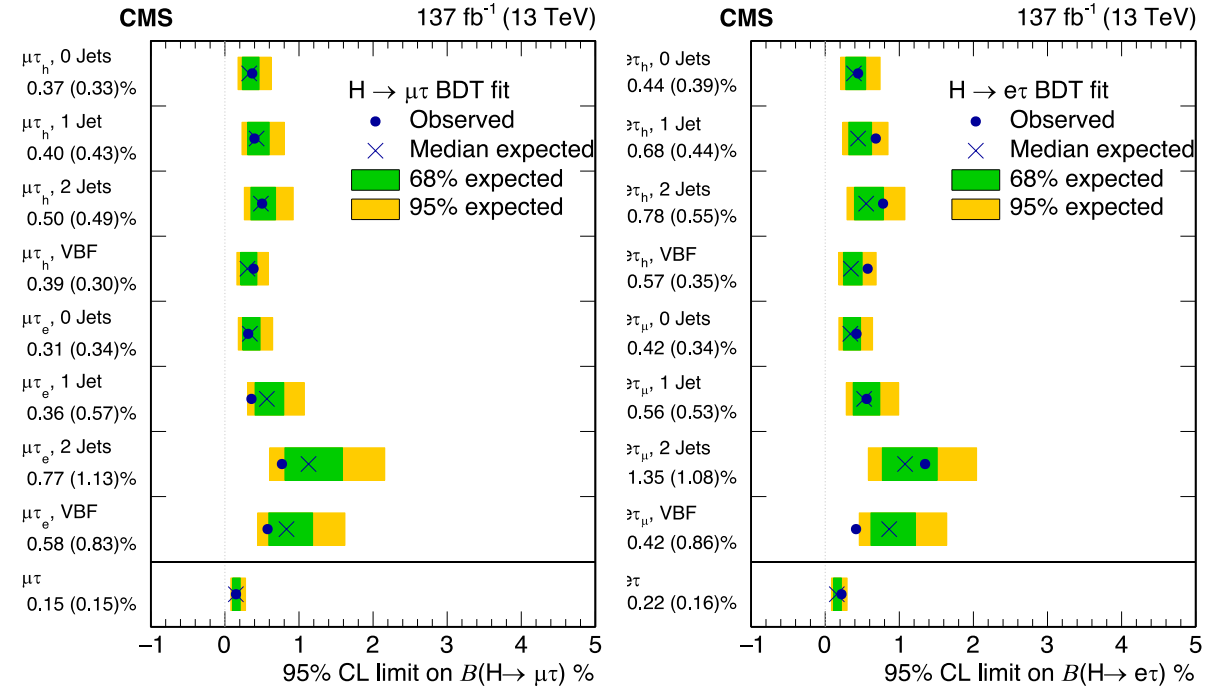
Excited b* quarks are excluded at 95% C.L. with a mass < 4.0 TeV (4.0 expected)

LFV decays of the Higgs boson to μτ and eτ

- 4 classes of decays ($\mu\tau_e$, $\mu\tau_h$, $e\tau_\mu$, $e\tau_h$) x 4 categories based on jets (0, 1, 2 gg fusion and 2 VBF)
- No significant excess has been found, upper limits on LFV BF are derived
- The observed and expected upper limits (95% CL) on the branching fractions are:
  - $(H\rightarrow\mu\tau) < 0.15\%$ (expected 0.15%)
  - $(H\rightarrow e\tau) < 0.22\%$ (expected 0.16%)

arXiv:2105.03007

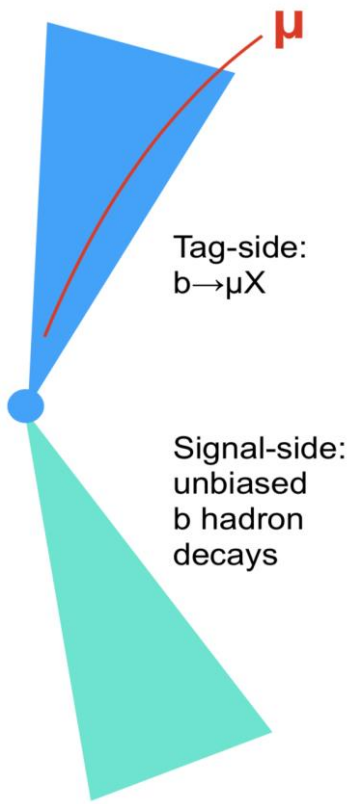




B-parking

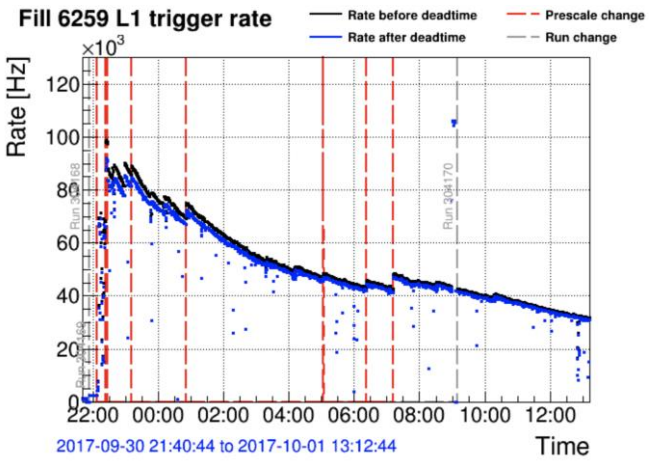
Idea in 2018 was to use low p_T single muon displaced triggers to save a sample of unbiased B hadron decays

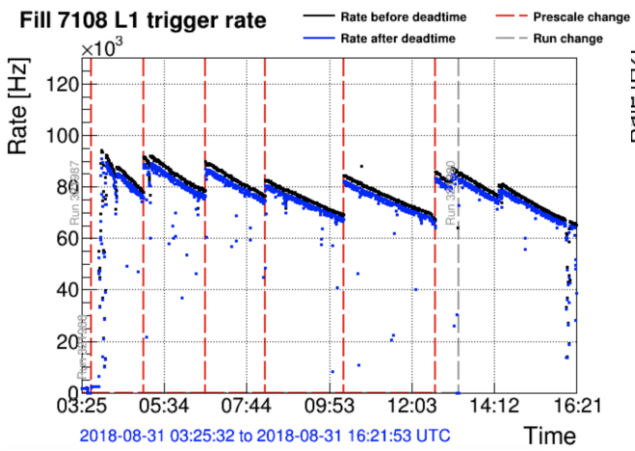
Need L1 low low p_T single muon trigger that can be enabled when lumi decreases

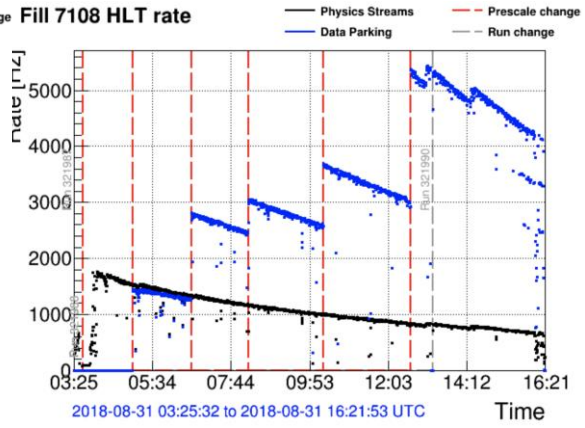


L1 trigger rate **HLT rate**

Standard **With additional low p_T muon**







Could record billions of unbiased B decays

Mode	N_{2018}	f_B	$\mathcal{B}$
Generic b hadrons			
B^0_d	4.0×10^9	0.4	1.0
$B^\pm$	4.0×10^9	0.4	1.0
B_s	1.2×10^9	0.1	1.0
b baryons	1.2×10^9	0.1	1.0
B_c	1.0×10^7	0.001	1.0
Total	1.0×10^{10}	1.0	1.0
Events for R_K and R_{K^*} analyses			
$B^0 \to K^* \ell^+ \ell^-$	2600	0.4	6.6×10^{-7}
$B^\pm \to K^\pm \ell^+ \ell^-$	1800	0.4	4.5×10^{-7}

- Enables more analyses on LFU violation
  - Several in progress
  - Expect first approved results soon
- Currently studying how to further optimize the trigger in Run 3

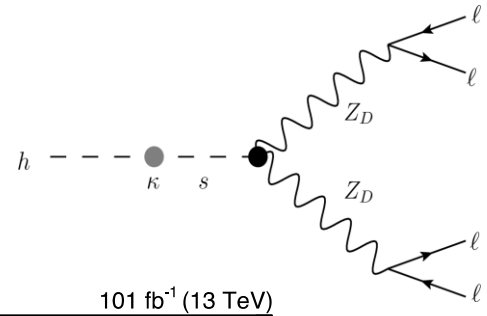
Scouting

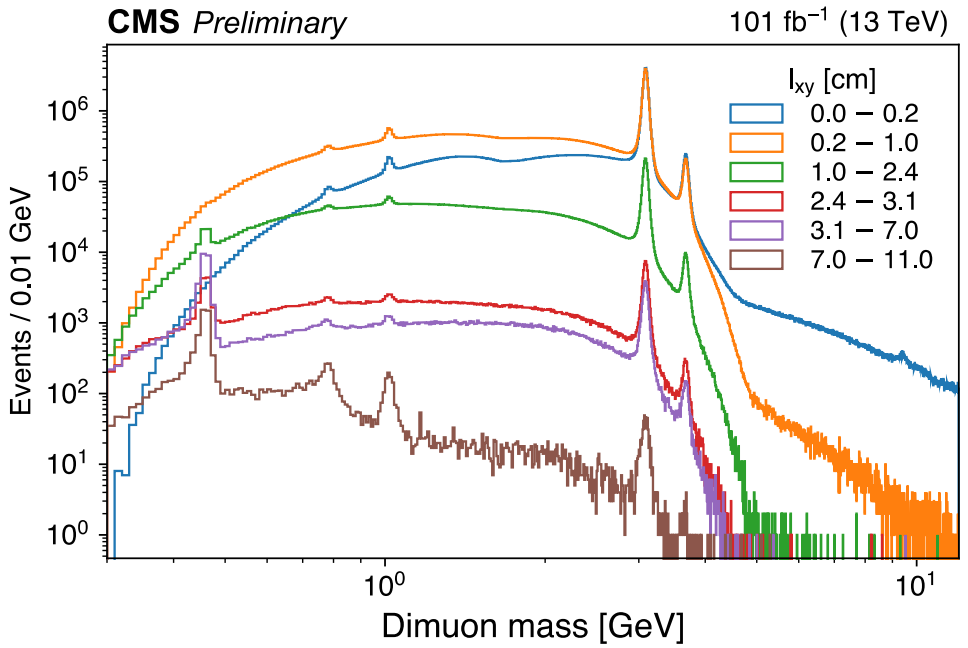
- Analysis based on a reduced data format and on the online reconstruction in the HLT farm
  - Do not save the full event data
- In Run 2 all analyses based about 5 kHz (~1 kHz of Particle Flow scouting)
- For Run 3 aim at running PF on higher rate, possible adding additional L1 triggers
  - Profit of GPUs and pixel tracks for the reconstruction

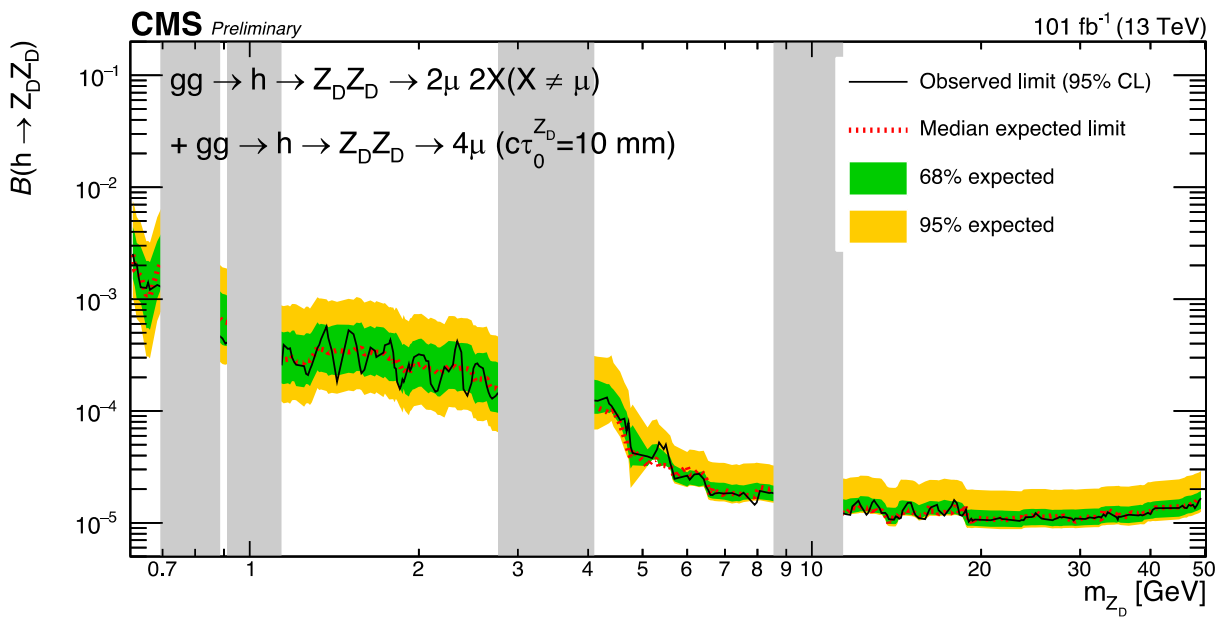
Recent Run 2 analysis based on scouting data: CMS-PAS-EXO-20-014

l_{xy} is the transverse vertex displacement, $0.1 < l_{xy} < 11$ cm

Example of the decay $h \to Z_D Z_D \to 4l$





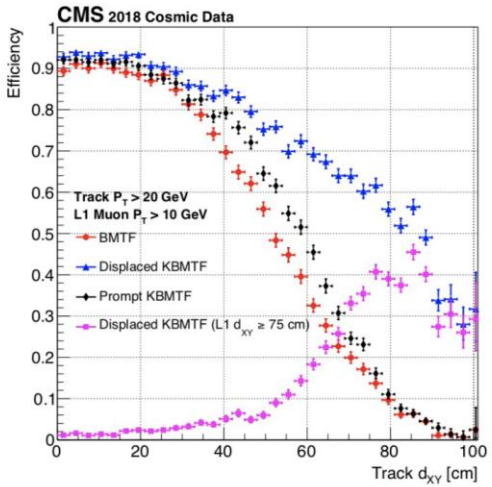


No signal observed and 95% exclusion limits derived

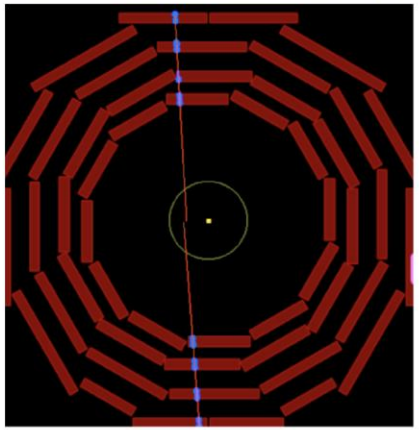
LLP improvements for Run 3

- Ongoing developments in the L1 trigger area with the aim to increase efficiency for displaced signatures
  - Increase efficiency for displaced muons
  - Extend muon triggers to hadronic showers
  - Out of time ECAL and HCAL at L1
  - Using HCAL depth information
- HLT developments also ongoing
  - Profit of new L1 triggers under development
  - Improve efficiency for displaced signatures in standard triggers

Kalman filter at L1

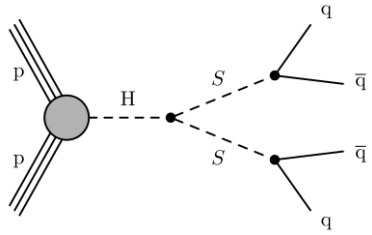


tested in parallel in 2018 and commissioned with cosmic rays



Search for LLPs using muon CSC detector as a calorimeter
The number of hits in the CSC is used
Events are triggered using transverse missing momentum pointing towards the CSC hit cluster

arXiv:2107.04838



Looking for a SM Higgs boson decaying into a pair of long-lived scalars