CMS status report

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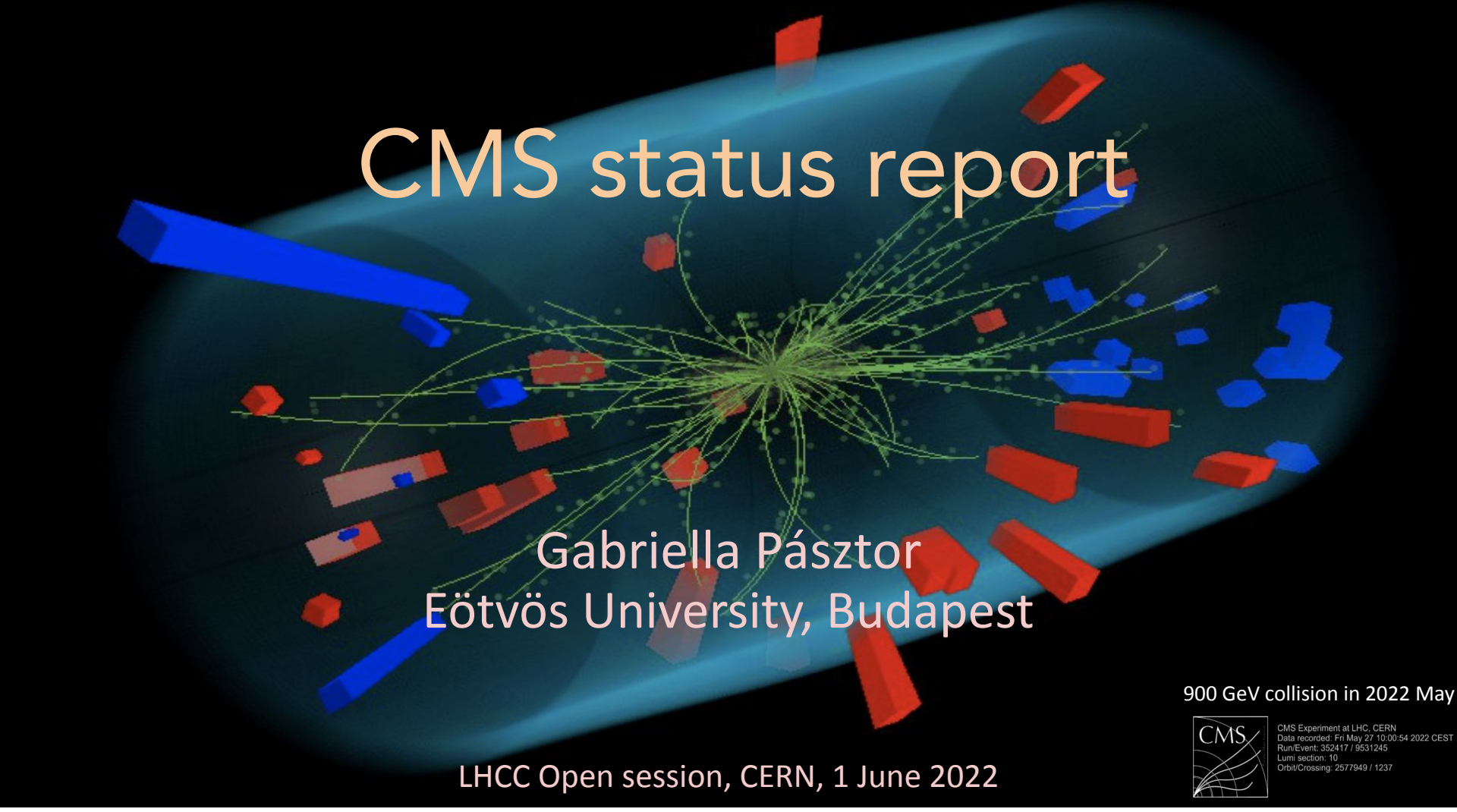
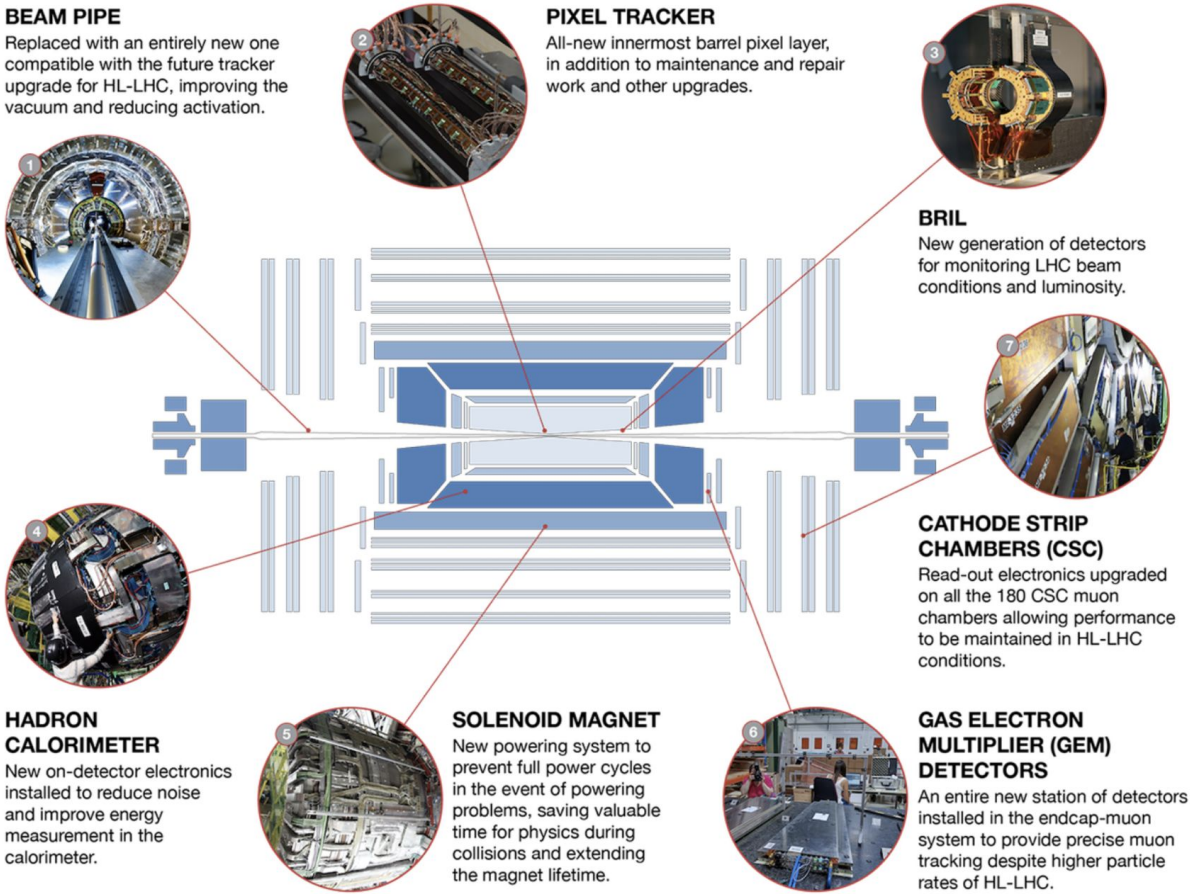


LHCC Open session, CERN, 1 June 2022

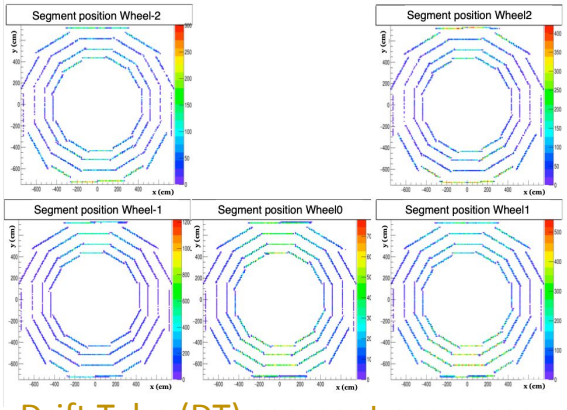
After extensive work in LS2, CMS ready for Run 3



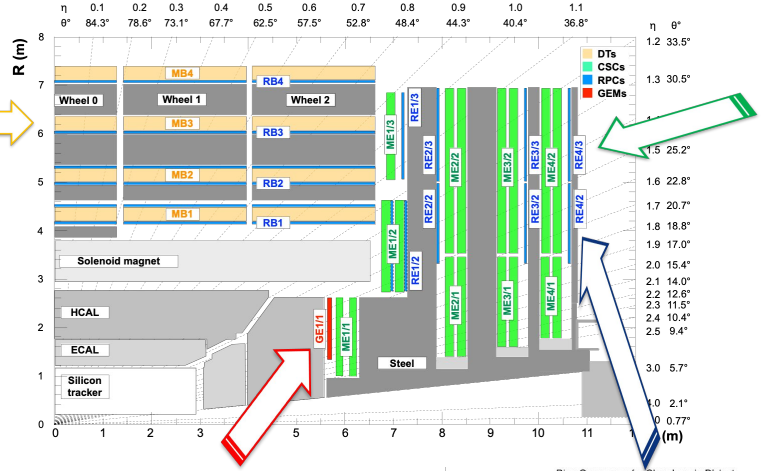
- Phase-2 muon and BRIL demonstrators installed
- Magnet recommissioned @3.8 T
- Pilot beam test program completed
- 2nd round of cosmics data taking
  - More than 6M tracks
  - Alignment & calibration
  - Efficiency scan of GE1/1
  - Validation of Pixel Layer 1
  - Exercise GPU @ HLT
- Successfully recorded splashes and collisions at 900 GeV

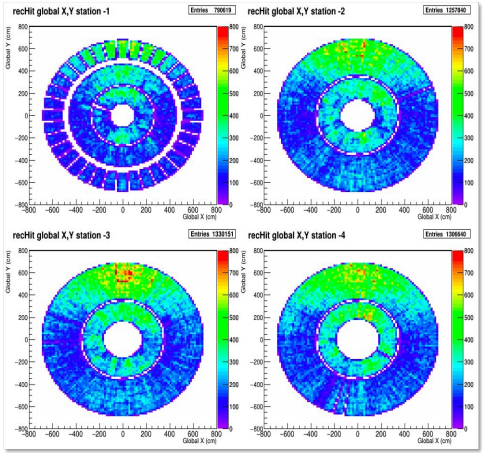
BRIL: Beam Radiation Instrumentation and Luminosity system, GE1/1: 1st layer of GEM detector, GPU: Graphical Processor Unit, HLT: High-Level Trigger, LS: long shutdown

Muon Spectrometer: all systems with expected performance



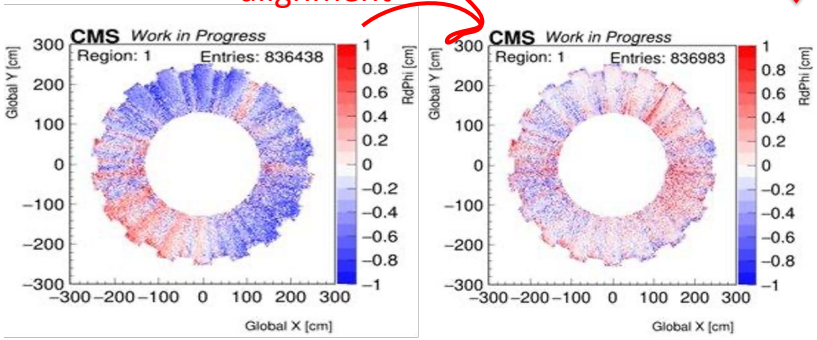
Drift Tube (DT) segment occupancy associated to standalone muons



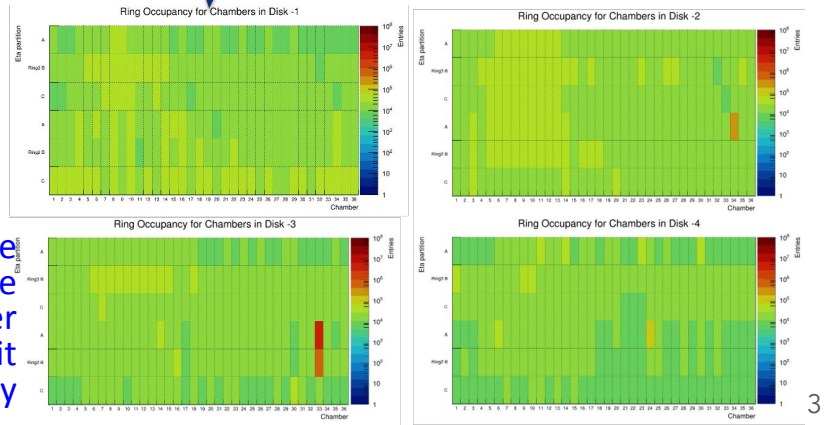


Cathode Strip Chamber (CSC) rechit occupancy

alignment



Residual map of GE1/1 super-chambers relative to the ME1/1 geometry

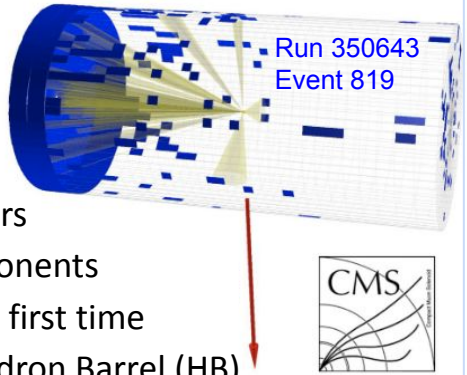


Resistive Plate Chamber (RPC) hit occupancy

Calorimeters: ready to go

Hadron Calorimeter (HCAL)

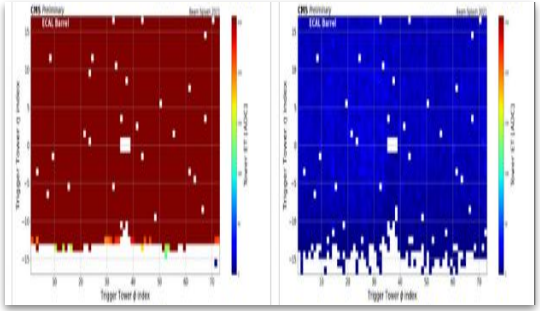
- Everything works as expected, no showstoppers to be ready for physics!
- 1st collision data being used to fine-tune the detectors



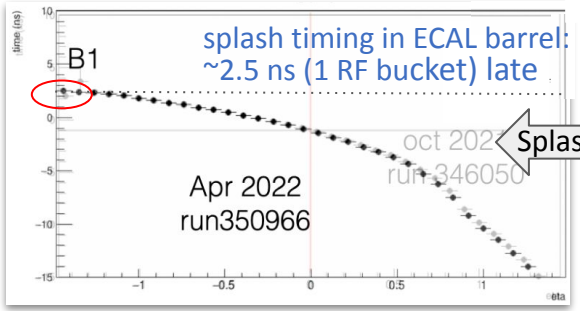
- Some components used for the first time
  - New Hadron Barrel (HB) front-end electronics
  - Forward Calorimeter (HF) switched to multi-mode optical transceivers & fibers

Electromagnetic Calorimeter (ECAL)

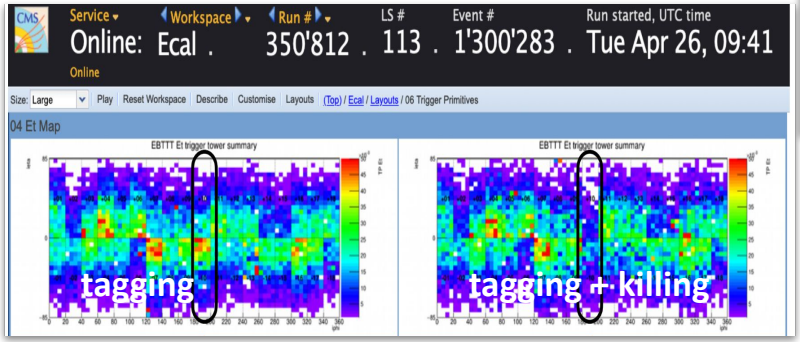
Occupancy: trigger tower η vs. φ

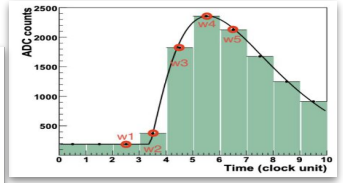


Time of arrival (ns) vs. η



Test of new "double-weights" algorithm to be introduced in Run 3 tagging out-of time (OOT) signals and rejecting spikes





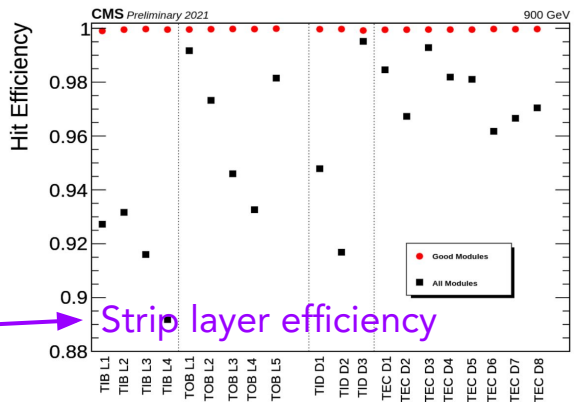
2nd set of linear weights in L1 trigger logic tuned to flag OOT signals and spikes due to particles hitting directly the APD

Mean E_T / event decreases due to suppression of early signals of ECAL Barrel (EB) strips (5 crystals) or towers (5x5 crystals) by "spike killing"

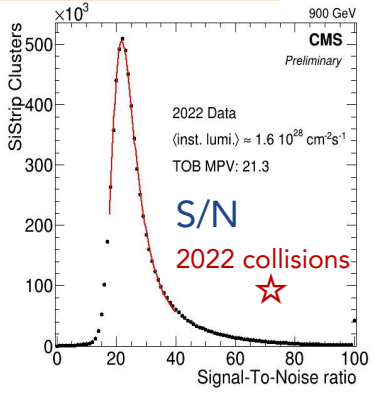
RF: radio frequency, APD: avalanche photodiode

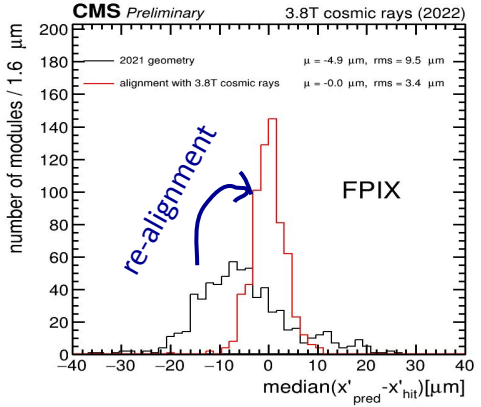
Silicon Trackers: recommissioned with cosmics & collisions

- Detector Control System upgraded & ready for Run 3
- Participate in cosmic ray data-taking
- Remain in standby during beam commissioning
- Performance evaluated with 900 GeV stable beam data
- **Strip Tracker:**
  layer-by-layer efficiency for good modules >99.8%
- **Pixel Tracker**: active pixel fraction is 98.7%
  - Layer-1 design changes validated (except efficiency at high pile-up)
- Alignment ready for collisions
  - Derived from cosmic rays and 900 GeV collision data in 2021: excellent performance
  - Magnet cycle during winter break and repeated temperature cycles during strip maintenance generated movements
  - **Re-aligned using >6.6M cosmic muons in 2022**
    - Pixel detector at module level
    - Strip detector at half-barrel / endcap structure level

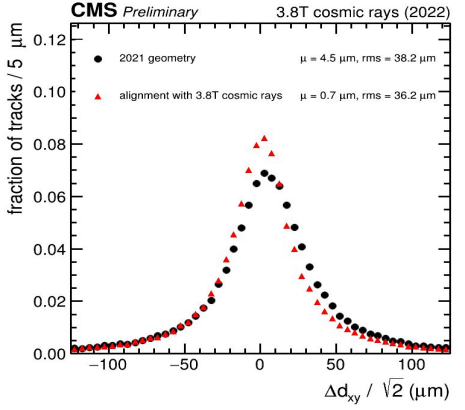


Strip layer efficiency





Median track-hit residuals per module: quantifies the accuracy of module positions for a given alignment



Impact parameter difference for incoming and outgoing tracks produced by the same cosmic ray muon

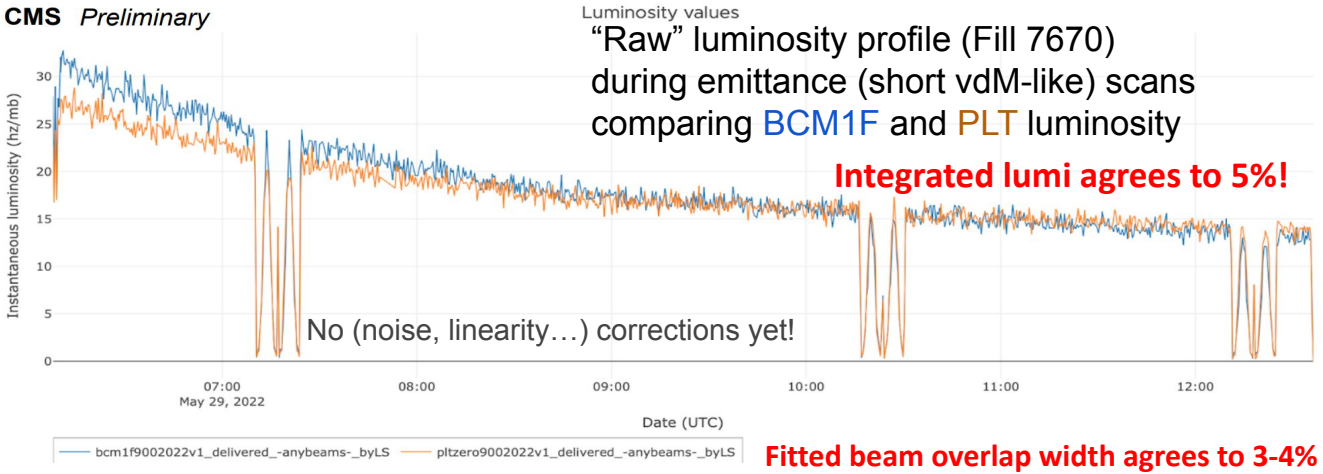
FPIX: Forward Pixel Detector, TOB: Tracker Outer Barrel, MPV: most probable value

Beam Radiation Instrumentation and Luminosity (BRIL)

14 technical systems for

- ❑ beam loss (abort),
- ❑ beam timing,
- ❑ beam induced background,
- ❑ luminosity,
- ❑ radiation monitoring

ready for collisions

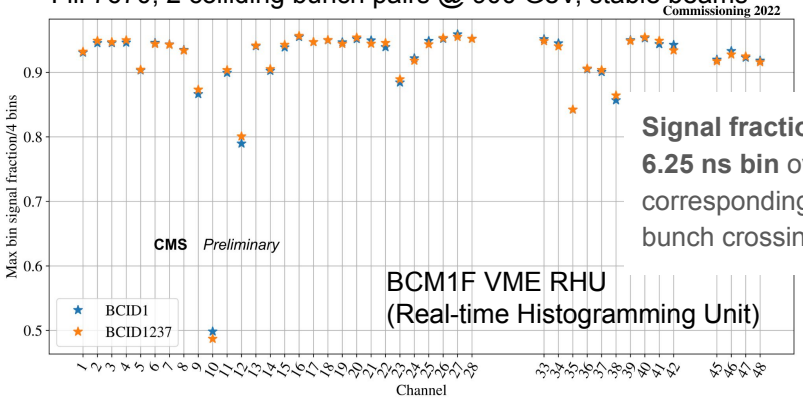


"Raw" luminosity profile (Fill 7670) during emittance (short vdM-like) scans comparing BCM1F and PLT luminosity

Integrated lumi agrees to 5%!

No (noise, linearity…) corrections yet!

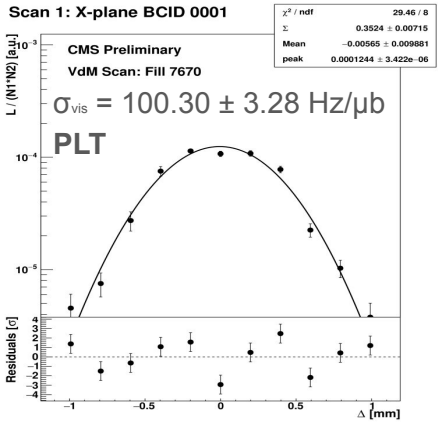
Fill 7670, 2 colliding bunch pairs @ 900 GeV, stable beams

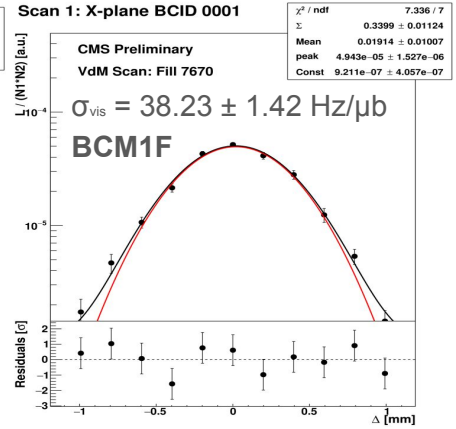


Signal fraction in the single 6.25 ns bin over all four bins corresponding to the filled bunch crossing

BCM1F VME RHU
(Real-time Histogramming Unit)

Fitted beam overlap width agrees to 3-4%



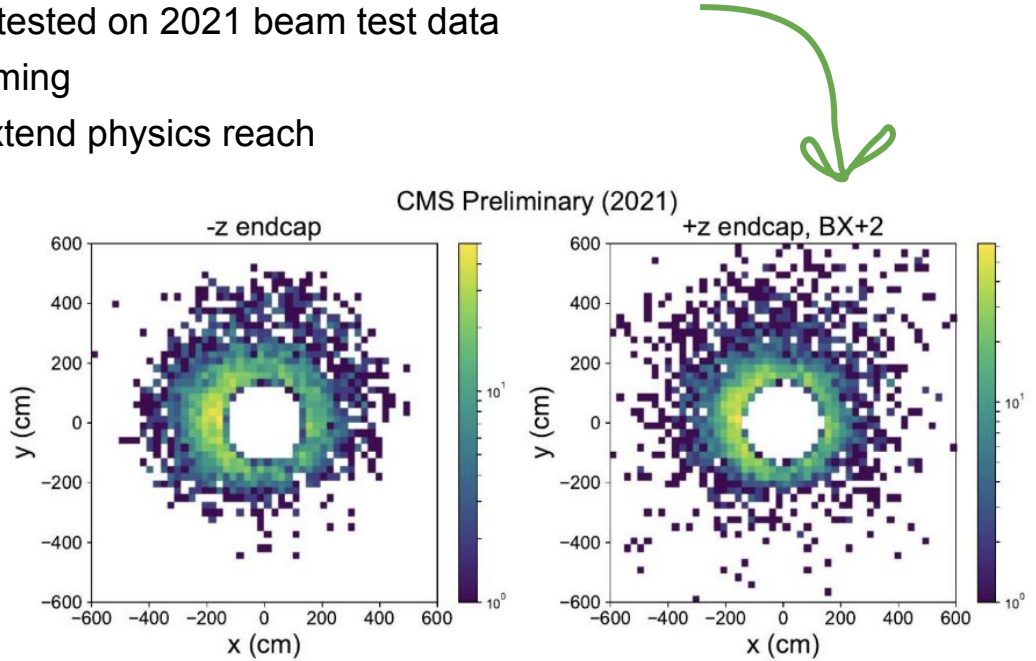


BCM1F: fast Beam Conditions Monitor, PLT: Pixel Luminosity Telescope, VME: Versa Module Europe standard, BCID: bunch crossing identifier

Level-1 Trigger & High Level Trigger (HLT)

Lots of developments!

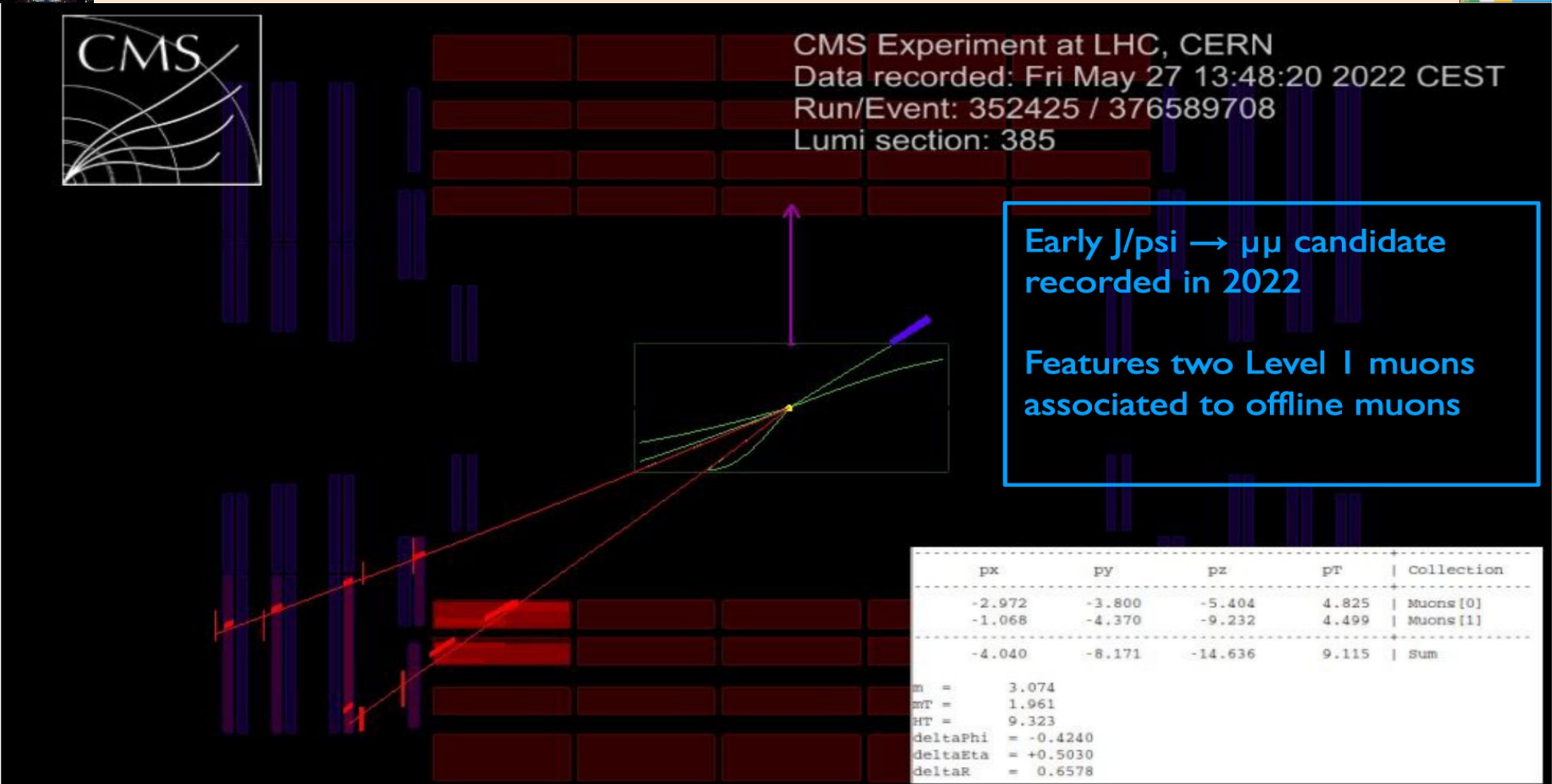
- ❑ New algorithms for displaced signatures taking advantage of new detector features
- ❑ GEM integration (with CSC) progressing well
- ❑ 40 MHz scouting demonstrators installed & tested on 2021 beam test data
- ❑ GPU transition significantly improves HLT timing
- ❑ Ambitious b-physics and parking plans to extend physics reach
- ❑ Level-1 & HLT menus close to final
- ❑ New HLT menu includes many improvements and new features, e.g., Deep NN and ParticleNet for object reconstruction and identification (b-tagging, tau, boosted objects..)
- ❑ 900 GeV collision data being scrutinized
  - ❑ Physics menus have been deployed smoothly



beam halo muons

GEM: Gas Electron Multiplier, CSC: Cathode Strip Chamber, GPU: Graphical Processor Unit, NN: neural network

Trigger validation with 2022 900 GeV collision data



Early J/psi → μμ candidate recorded in 2022

Features two Level 1 muons associated to offline muons

	px	py	pz	pT	Collection
	-2.972	-3.800	-5.404	4.825	Muons[0]
	-1.068	-4.370	-9.232	4.499	Muons[1]
	-4.040	-8.171	-14.636	9.115	Sum

```
m   =      3.074
mT  =      1.961
HT  =      9.323
deltaPhi   = -0.4240
deltaEta   = +0.5030
deltaR     =  0.6578
```

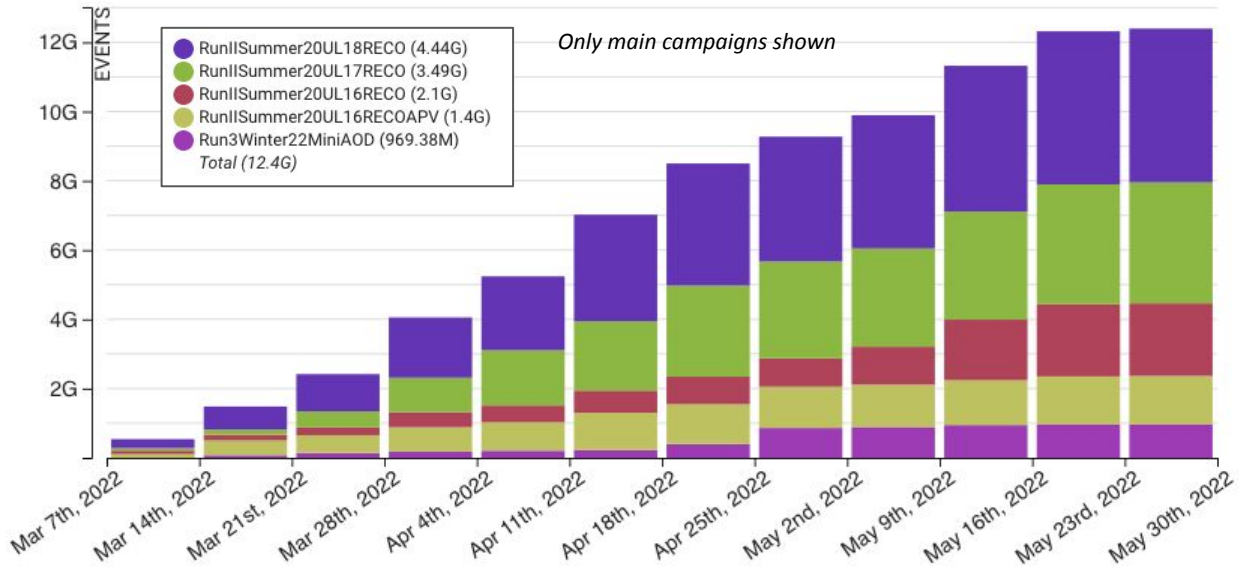
PPD developments for Run 3

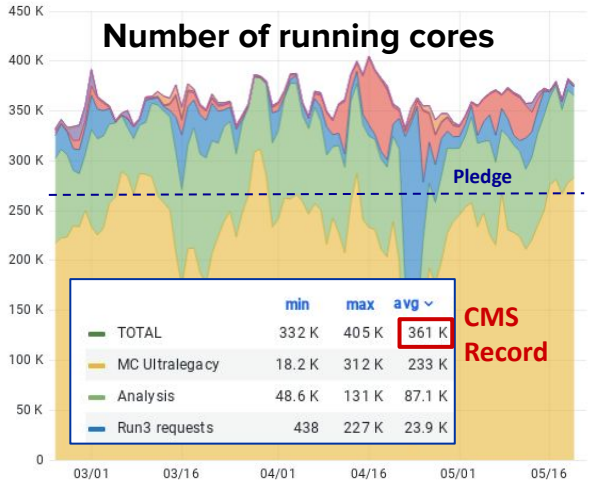
CMS **“Physics Performance and Dataset”** (PPD) group ready for collisions!

- Critical tasks completed
- Improvements ongoing for Data Quality Monitoring (DQM)
- Release and production plan well on track
- Run 2 ultra legacy Monte Carlo (MC) production close to complete
- Reconstruction code for 13.6 TeV collisions nearly finalised
- Preparing to launch 10B MC events for physics analysis

GrASP: Group Analysis Samples Page, GUI: graphical user interface, DC: Data Certification, ML: machine learning, MiniAOD: data format with 50 kB/event, NanoAOD: data format with 2 kB/event, AOD: Analysis Object Data

Production and Processing since March





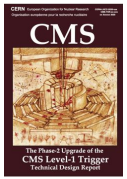
Excellent usage of resources!

- **~12 B G4-simulated independent events delivered to analysis and detector experts using 3 standard data formats**
  - AOD (500 kB/event) + MiniAOD (50 kB/event) + NanoAOD (2 kB/event)
- In addition, 2.6 B MiniAOD events coming from Re-MiniAOD campaigns
- CMS chose Alma Linux 8 for Run 3: identical OS and same software online & offline, minimizing maintenance effort

Another excellent quarter in terms of samples delivery!

AOD: Analysis Object Data

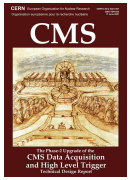
CMS Phase-2 Upgrade



Level-1 Trigger

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

- Tracks in L1 Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger

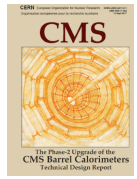
https://cds.cern.ch/record/2759072

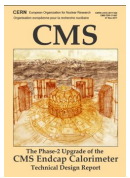
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Barrel Calorimeters

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

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

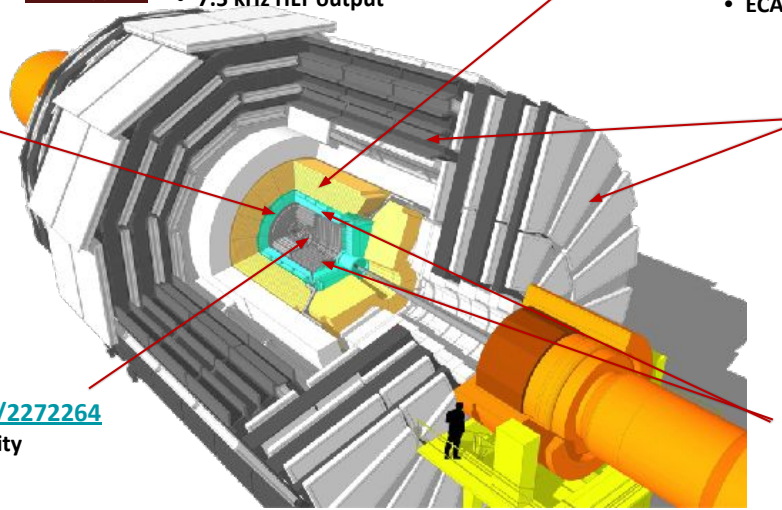




High-Granularity Calorimeter Endcap

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

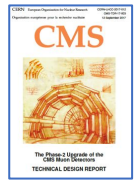
- 3D showers and precise timing
- Si, Scintillator+SiPM in Pb/Cu-W/SS

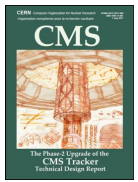


Muon systems

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

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





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

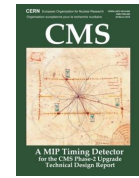
- Si-Strip and Pixels increased granularity
- Extended coverage to η ≃ 4
- Design for tracking in L1 Trigger

MIP Timing Detector

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

Precision timing with:

- Full coverage to η ≃ 3
- 30-50 ps time resolution for MIPs
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

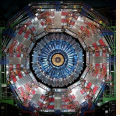


Beam Radiation Instrumentation and Luminosity

http://cds.cern.ch/record/2759074

- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors

SS: stainless steel, FE: front end, BE: back end, MIP: minimum ionizing particle, SiPM: Silicon Photomultiplier

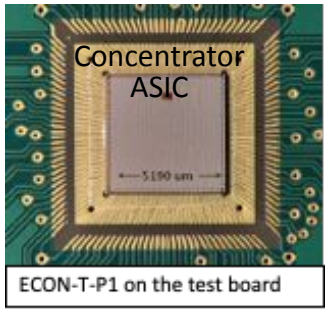


P2UG highlighted “impressive progress” since last review

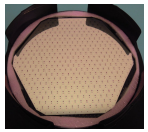
- Re-optimization of the Barrel Timing Layer (BTL) light output: packaging, ASIC (TOFHIR2B) & SiPM
- Muon system
  - Completion of the upgrade of the CSC frontend boards, low and high voltage systems
  - RE3/1+RE4/1 and GE2/1 demonstrators installed during LS2
  - RPC cross-talk issues fully resolved, very close to final Front-End Board design
- High Granularity Calorimeter (HGCal)
  - Excellent Si sensor quality, confirmation of radiation hardness, readiness for pre-production
  - Receipt of “partial” sensors that cover the inner and outer border regions
  - Progress with the production versions of the front-end ASIC designs
- Inner Tracker: decision on sensor design and use of 3D sensors for layer 1, excellent sensor test results
- Mechanics for HGCAL and (Outer & Inner) Tracker advancing well
- **Next year will be the pivot year for the project moving out of R&D into production**

CSC: Cathode Strip Chambers, RPC: Resistive Plate Chambers; R3&4: RPC station 3 and 4, GEM: Gas Electron Multiplier; GE2/1: GEM station 2, ASIC: Application Specific Integrated Circuit, TOFHIR2B: Time-of-Flight High Rate chip, SiPM: Silicon Photomultiplier, P2UG: Phase-2 Upgrades Groups

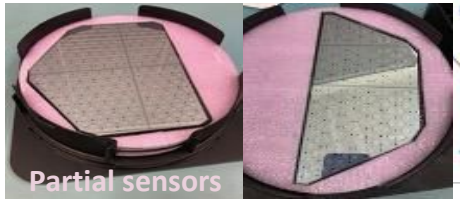
Phase 2 Highlights in Pictures



ECON-T-P1 on the test board



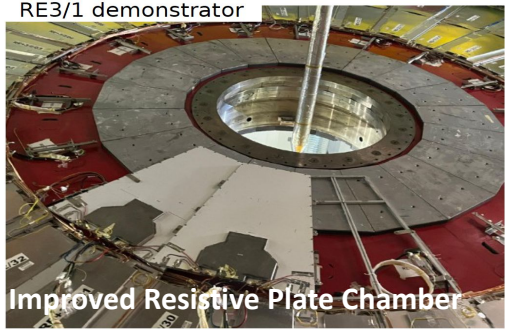
High-Granularity Calorimeter



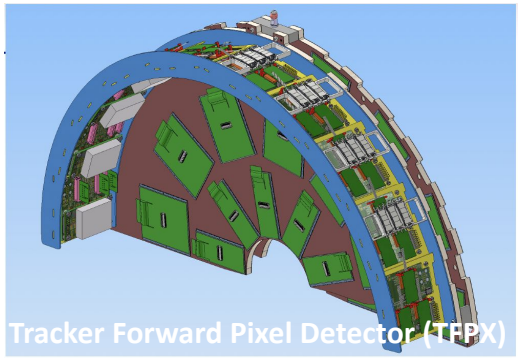
CE-H absorber structure, support wedges, and back-flange

GE2/1 demonstrator

RE3/1 demonstrator

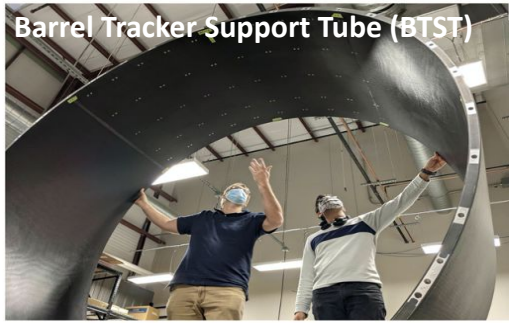


CROC: CMS Read-Out Chip, HPK / FBK / LFoundry / CNM: suppliers,
ECON-T: front-end concentrator chip for trigger path

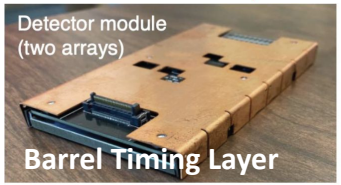


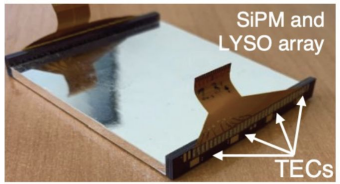
TFPX dee with the 10-portcards revised cartridge

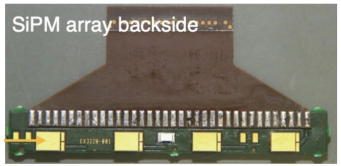
TRACKER INTEGRATION & SERVICES: BTST



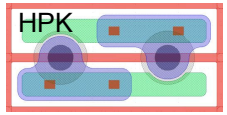
Full size 1m long BTST finished prototype at Purdue

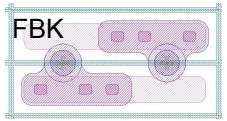


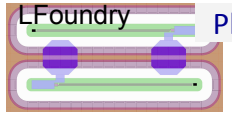




TEC: Thermo-Electric Cooler

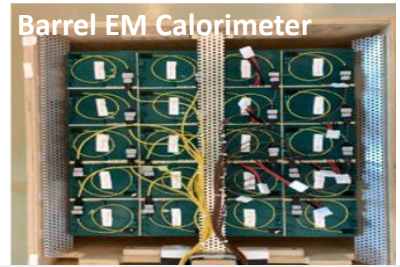




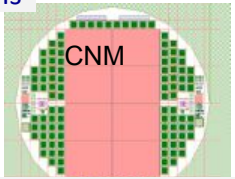


Planar Sensor Cells

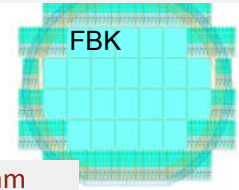
100x25 µm sensor cells everywhere in **Inner Tracker**



ECAL system for 400 channel testbeam



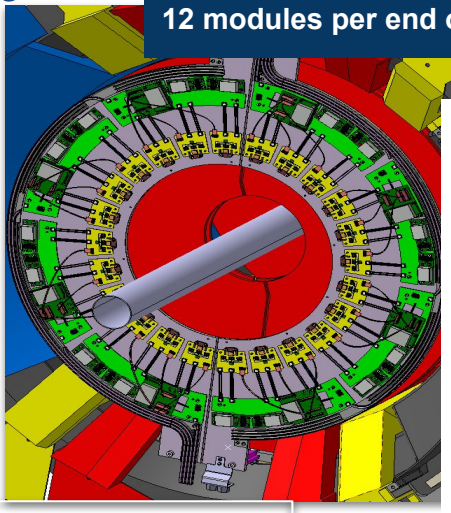
3D CROC Sensors

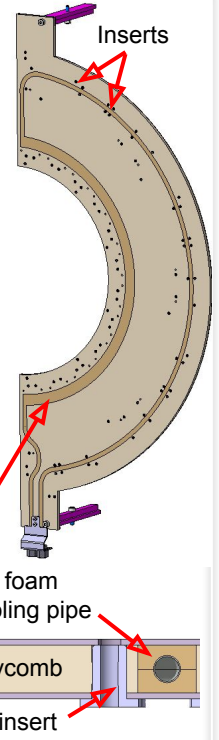


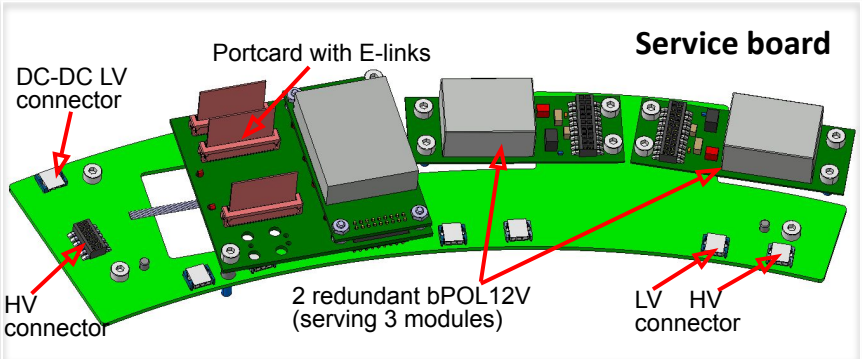
Fast Beam Condition Monitor evolution since TDR

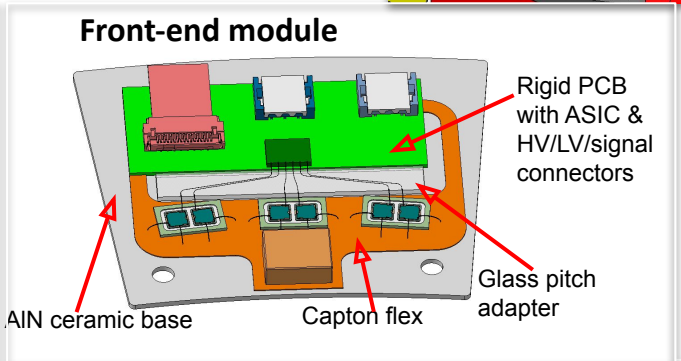
- Design of 6-channel ASIC started: optimised for fast time response & low noise
- Electronics system design reuse components from the Tracker
- Modular system
- 1 service board / 3 front-end modules (power, control, read out) at higher radius
- Mechanics follows IT design (materials & manufacturing, vendors) with minor modifications
- Working on finalising services and integration
  - Connect to Tracker Endcap Pixel (TEPX) detector cooling manifold, keeping independence from **dedicated** BRIL ring

2 identical half-disks with 12 modules per end of CMS





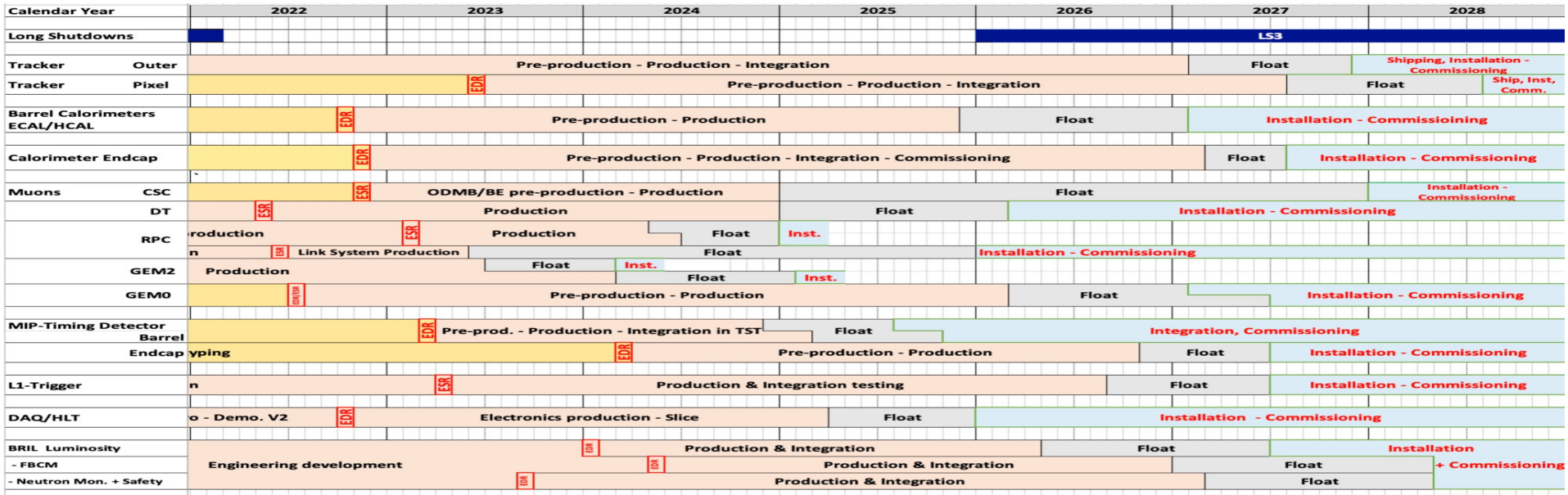




LV: low voltage, HV: high voltage, bPol12V: CERN-developed DC-DC converter, D4R1: Disk 4 Ring 1 of TEPX, AlN: Aluminum-Nitrid, CF: carbon fiber

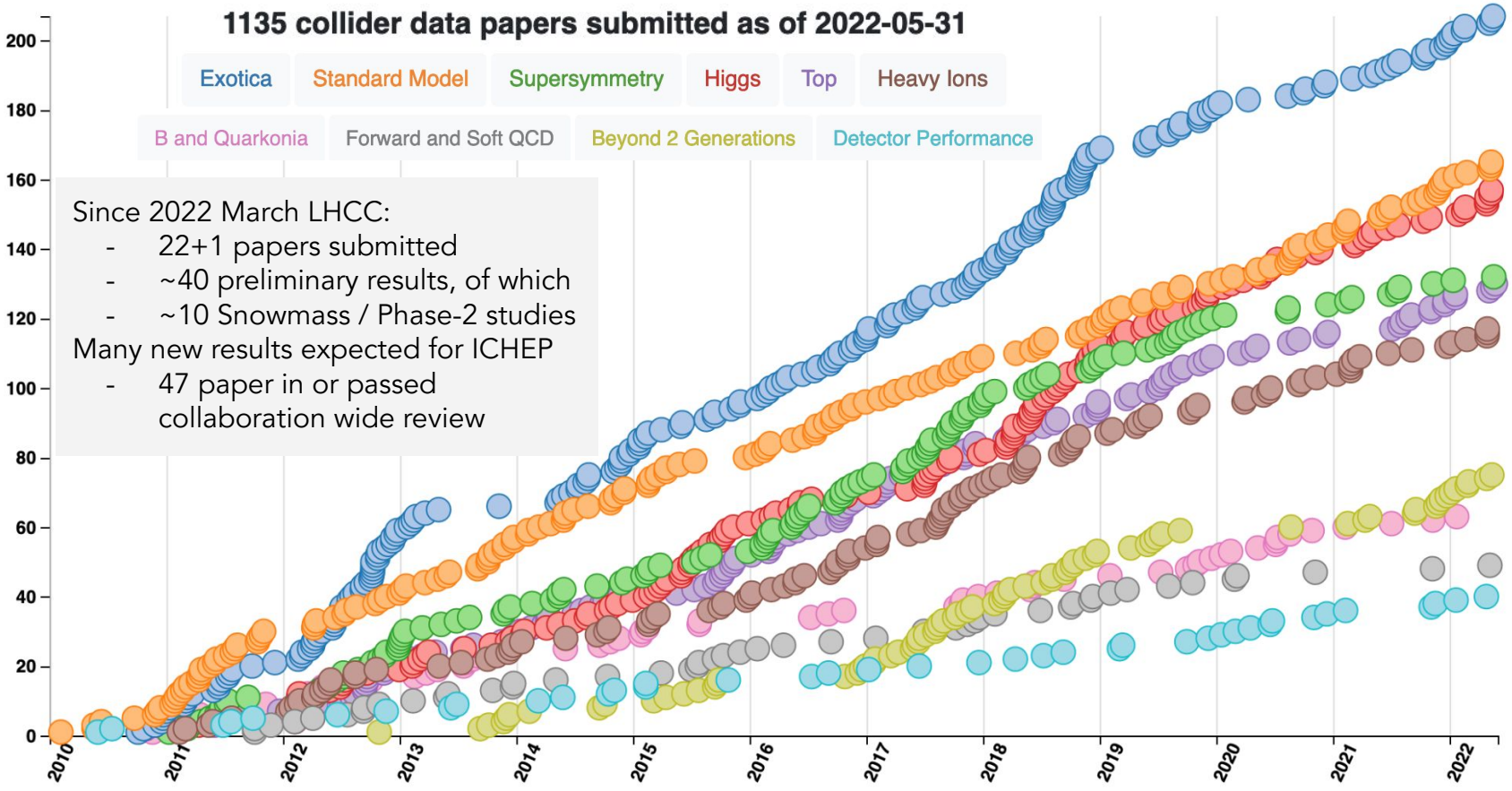
Phase-2 upgrade schedule re-baselined

- With the extension of Run 3 and LS3, CMS revisited the LS3 schedule at Point 5 and the schedules of individual projects in a bottom-up approach, followed by a top-down optimisation
- With positive contingency, the P2UG considers the new schedule as a potential viable baseline
- Several places were identified where the injection of **personpower** is mandatory to realise the schedule
- With **5 months float**, plus some internal float, the situation remains tight for HGCal
- The **war in Ukraine** has serious ramifications, especially for HGCal, adding uncertainties and risks



P2UG: Phase-2 Upgrades Groups, HGCal: High-Granularity Calorimeter, LS: long shutdown

Physics results



Since 2022 March LHCC:

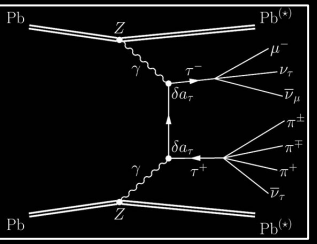
- 22+1 papers submitted
- ~40 preliminary results, of which
- ~10 Snowmass / Phase-2 studies

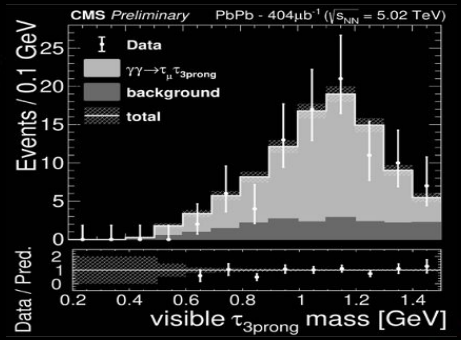
Many new results expected for ICHEP

- 47 paper in or passed collaboration wide review

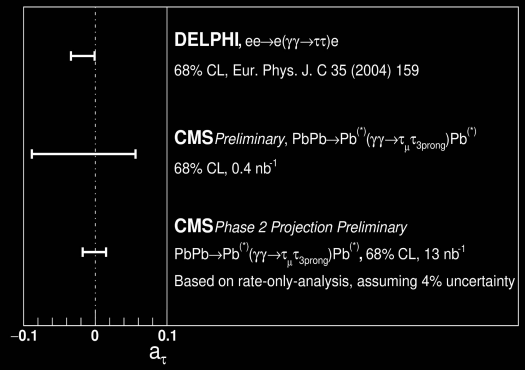
Lead beams as a light source: UPC $\gamma\gamma \to \tau^+\tau^-$

CMS Experiment at the LHC, CERN
Data recorded: 2015-Dec-06 21:41:27.033612 GMT
Run / Event / LS: 263400 / 88515785 / 849





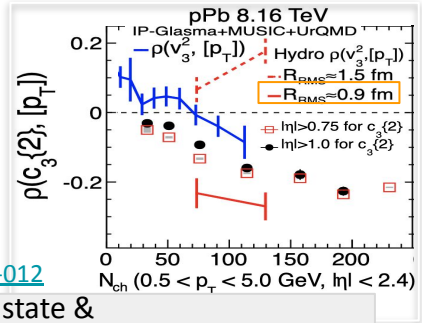
HIN-21-009



UPC: ultraperipheral collision

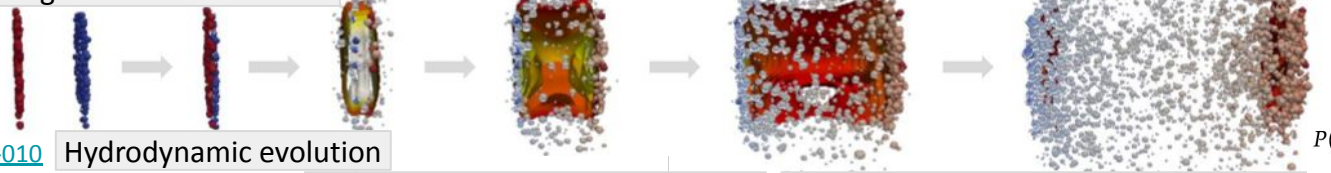
Pinning down the Standard Model of Heavy Ion collisions

correlator using 2-particle cumulant

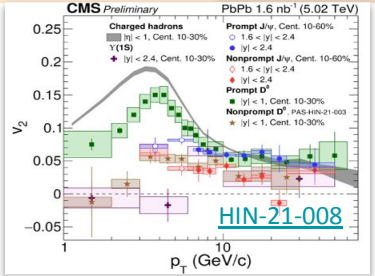


HIN-21-012

Initial state &
flow with higher-order cumulants



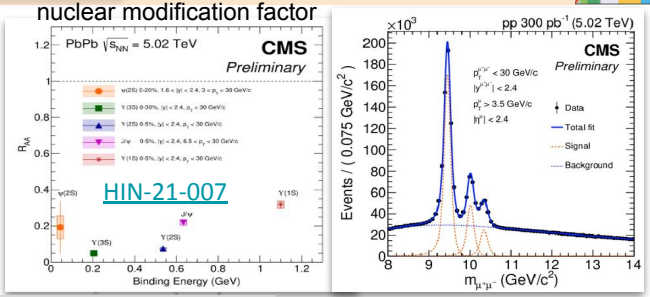
HIN-21-010 Hydrodynamic evolution



HIN-21-008

Azimuthal anisotropy:
improved heavy flavour v_2

nuclear modification factor



HIN-21-007

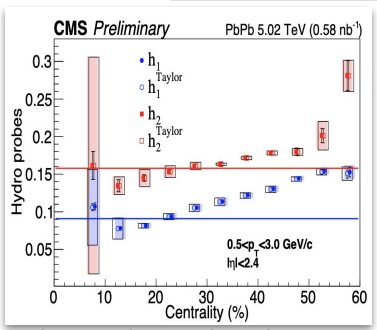
Sequential suppression

First observation
of Y(3S) in PbPb

$$P(\Delta r) = \frac{1}{\delta r}\frac{1}{N_{jet}}\Sigma_{jets}\Sigma_{trk\in(\Delta r_a,\Delta r_b)}p_T^{trk}$$

HIN-20-003

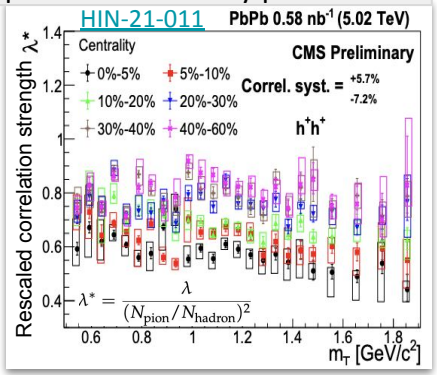
$$h_1 = (v_2\{6\} - v_2\{8\})/(v_2\{4\} - v_2\{6\})$$
$$h_2 = (v_2\{8\} - v_2\{10\})/(v_2\{6\} - v_2\{8\})$$



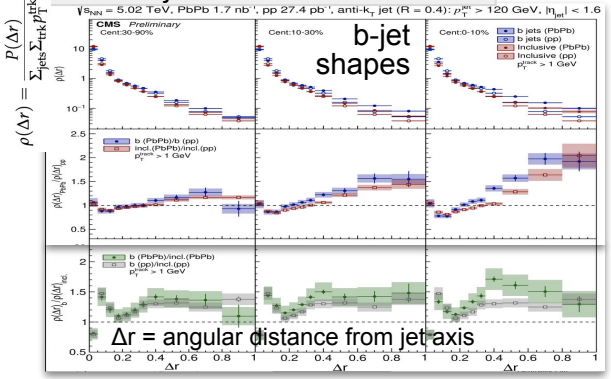
Interaction region shape
evolves with centrality

2-particle BEC & Levy parameters

HIN-21-011



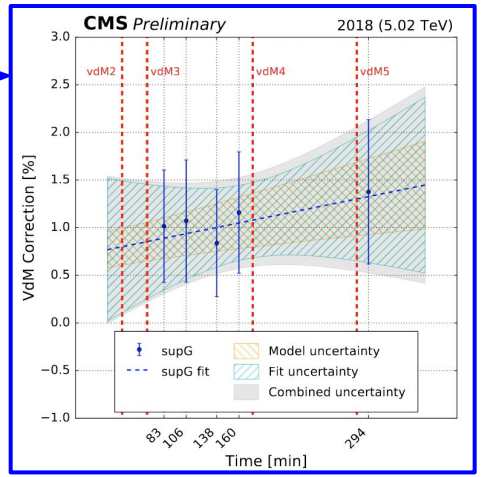
Flavour dependence of jet - medium interactions

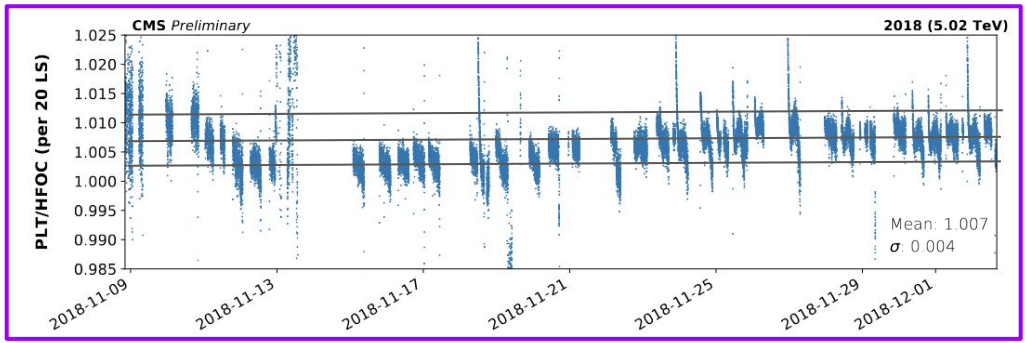


BEC: Bose - Einstein correlations

Luminosity calibration: PbPb @ 5.02 TeV (2018 Nov)

Source	Correction [%]	Uncertainty [%]
Normalization		1.3
Transverse factorizability	+1.0	0.8
Ghost and satellite charge	+3.9	0.5
Length scale calibration	−1.5	0.5
Scan-to-scan variation	—	0.5
Cross-detector consistency	—	0.4
Beam-beam effects	—	0.3
Systematic orbit distortion	—	0.2
Beam current calibration	—	0.2
Noncollision rate	−0.6	0.2
Random orbit distortion	−0.1	0.1
Statistical uncertainty	—	0.1
Integration		0.8
Cross-detector stability	—	0.8
Noncollision rate	—	0.1





Among most precise PbPb luminosity determinations

Three systems with independent calibration:

- ❑ Fast Beam Conditions Monitor (BCM1F)
- ❑ Forward Hadron Calorimeter (HFOC)
- ❑ Pixel Luminosity Telescope (PLT)

Stability monitored using emittance scans (short vdM-like scans)

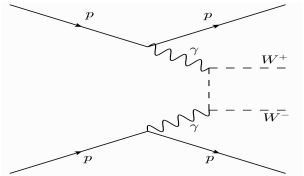
Total uncertainty: 1.5%

PAS-LUM-18-001

SupG: super-Gaussian function, vdM: van der Meer (beam-separation scan)

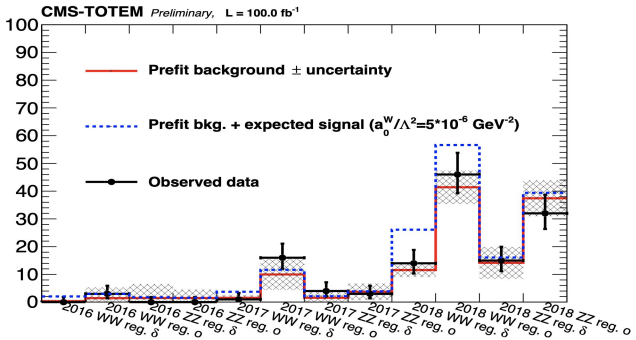
Exclusive physics with PPS: searches for rare processes

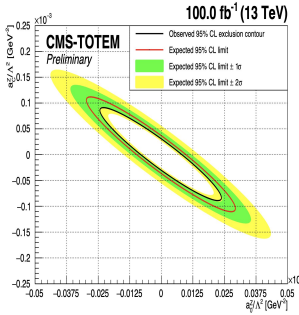
High-mass (m > 1 TeV) $\gamma\gamma \rightarrow$ WW/ZZ

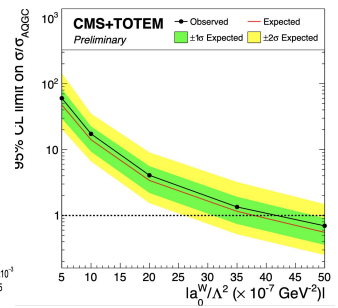


anomalous quartic gauge couplings in dim-6 & dim-8 EFT

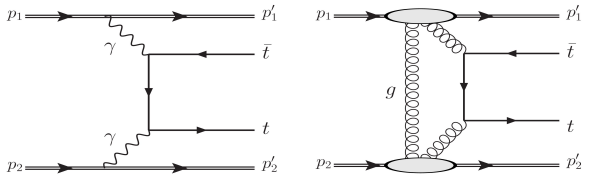
SMP-21-014

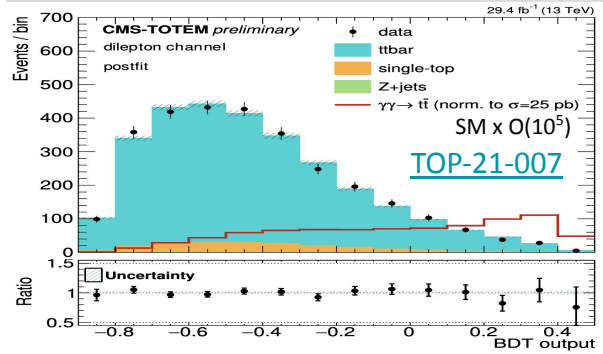




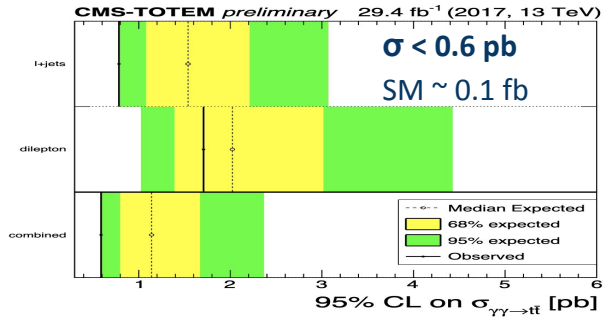


CEP top-pair production (OS 2ℓ & ℓ+jets)



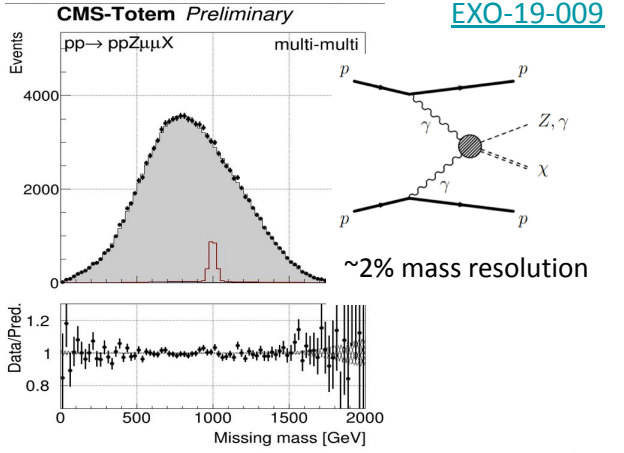


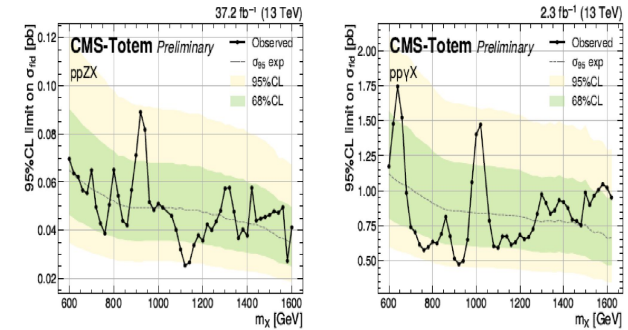
TOP-21-007



Exotic particle search via missing mass

EXO-19-009





Proton reconstruction performance

PRO-21-001

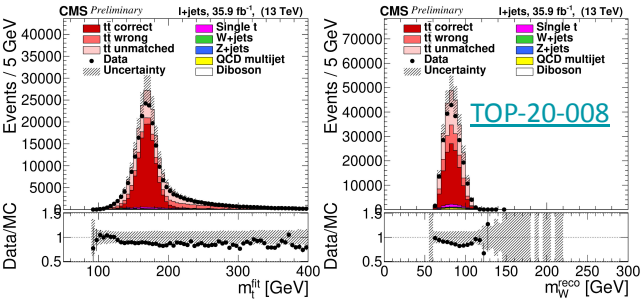
PPS: precision Proton Spectrometer, CEP: central exclusive production, EFT: effective field theory, OS: opposite charge (sign)

For more: PPS seminar

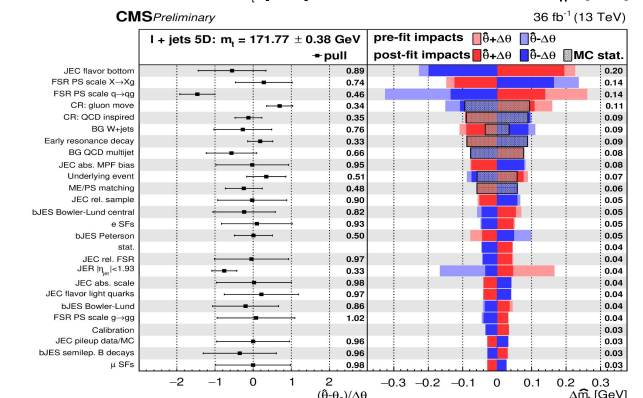
New top mass measurements (+ cross-sections in backup)

Direct measurement in tt (ℓ+2b+≥2j)

- Reco mass from kinematic fit
- Up to 5 variable profile LH fit
- Constrain jet uncertainty with W
- $m_t = 171.77 \pm 0.38$ GeV

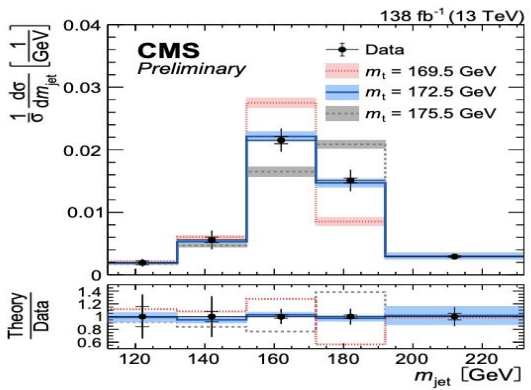


TOP-20-008



Jet mass unfolded to particle level for boosted top (ℓ+jets)

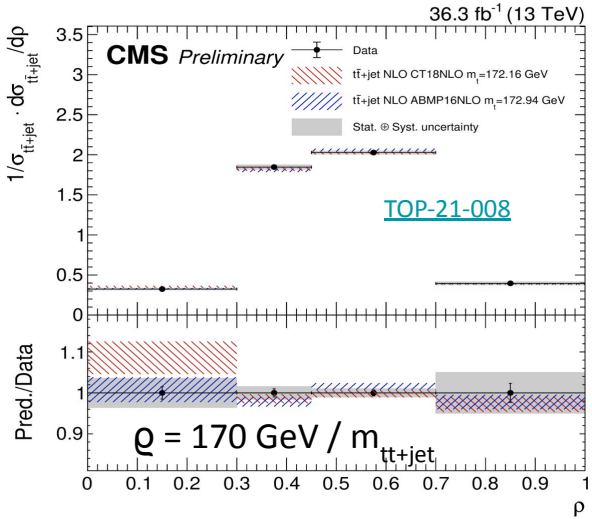
- Jet mass calibrated with hadronic W reco as large-R jet
- FSR uncertainty by angular correlations of jet substructure
- $m_t = 172.76 \pm 0.81$ GeV
- Competitive & complementary
- Can be used to extract pole mass if jet mass calculations appear



TOP-21-012

m_t^{pole} from tt+jet (OS 2ℓ)

- 1/m diff xsec unfolded to parton level
- Compare to NLO w. pole mass renorm
- ABMP16NLO:
  $m_t^{pole} = 172.94^{+1.37}_{-1.34}$ GeV
- CT18NLO:
  $m_t^{pole} = 172.16^{+1.44}_{-1.41}$ GeV



TOP-21-008

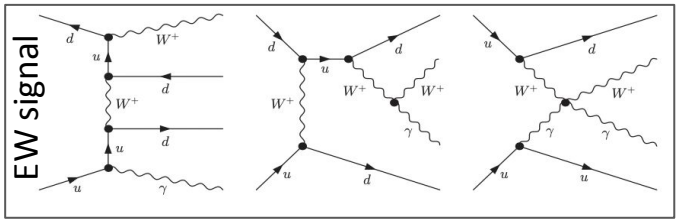
CMS Run1 legacy: 172.44 ± 0.13 ± 0.47 GeV

R: angular distance, NLO: next-to-leading order, ABMP16NLO / CT18NLO: parton distribution function sets

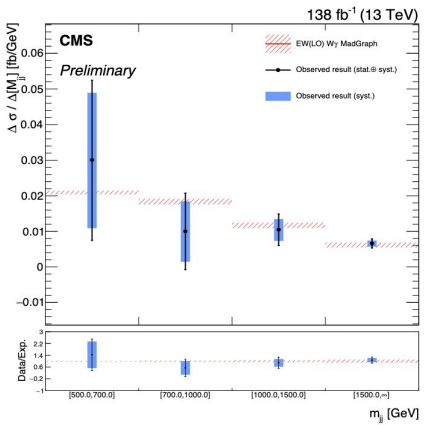
Di-boson production: electroweak & double parton scattering

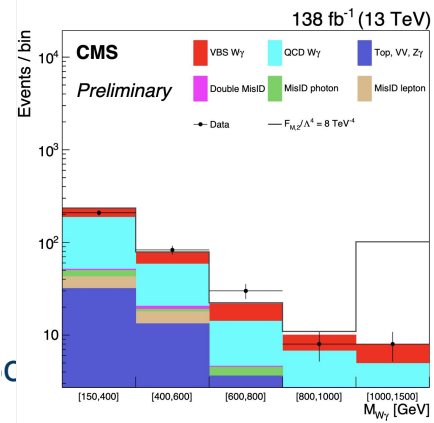
EW Wγ + 2 jets production (W→$\ell\nu$)

SMP-21-011

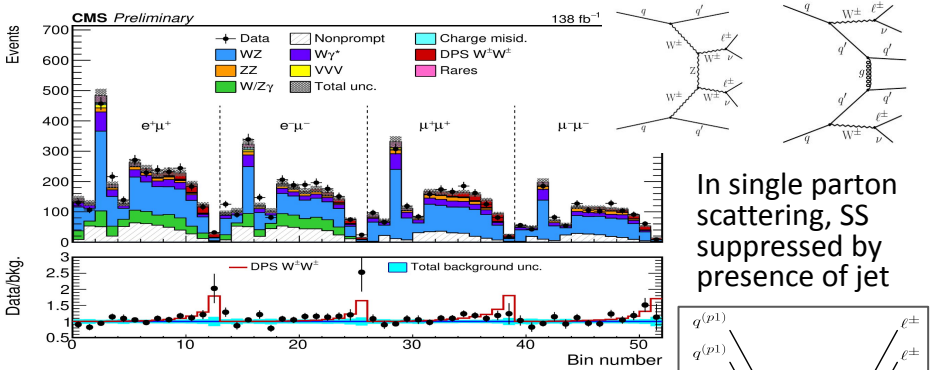


Inclusive and EW cross-section in fiducial region
First differential cross-sections unfolded to parton level
Competitive limits on anomalous QGCs in dim-8 EFT

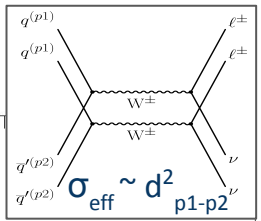




Same-sign WW from double parton scattering



In single parton scattering, SS suppressed by presence of jet



1st observation:
6.2σ
(6.7 σ expected)

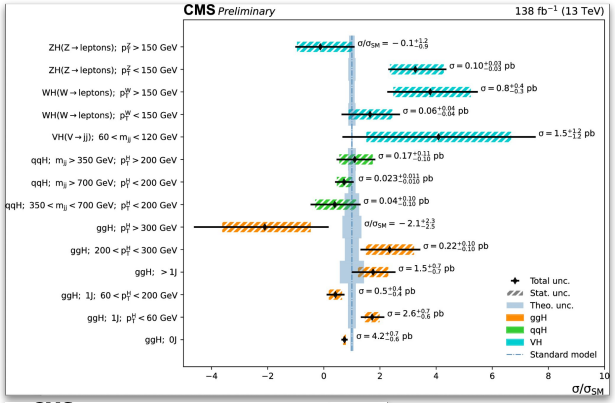
$$\sigma_{AB}^{DPS} = \frac{n}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

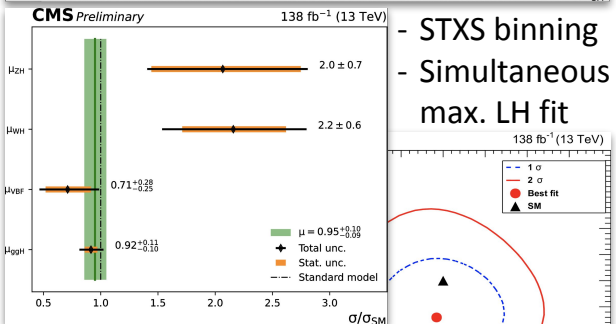
SMP-21-013

EW: electroweak, QGC: quartic gauge coupling, EFT: effective field theory, DPS: double parton scattering

Many new results for 10 year anniversary of Higgs discovery

H → WW cross-section HIG-20-013

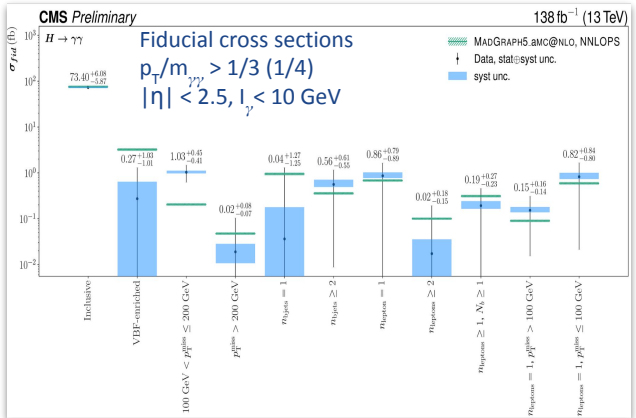


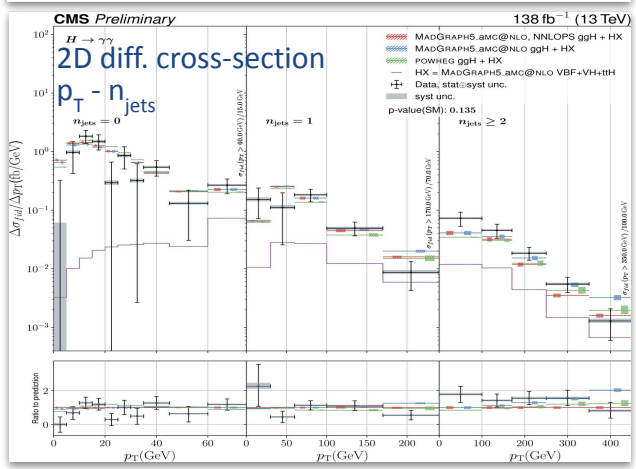


- STXS binning
- Simultaneous max. LH fit

STXS: simplified template cross sections, LH: likelihood

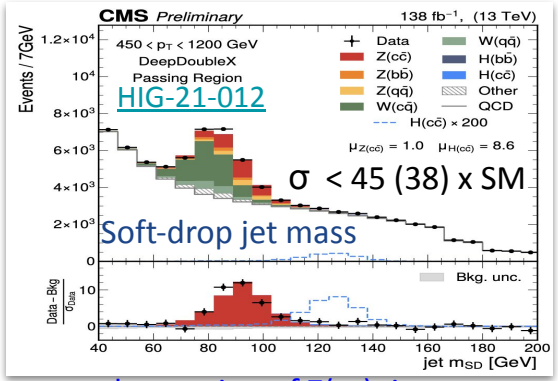
H → γγ cross-section HIG-19-016



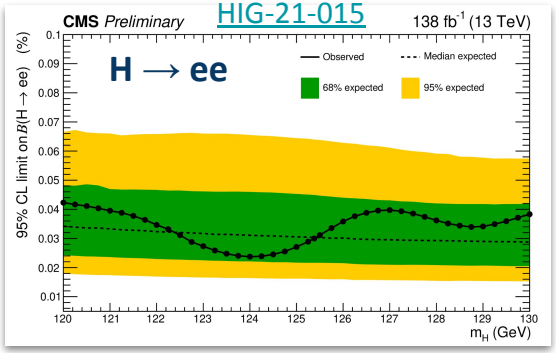


Search for rare decays HIG-21-008

after the VH(cc) search (σ < 14 (7.6) x SM)
an **inclusive search for boosted H → cc**



+ observation of Z(cc)+jets

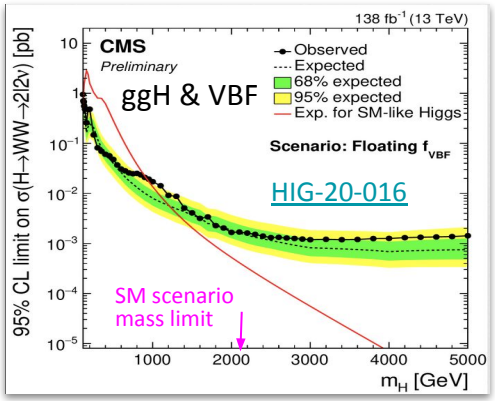


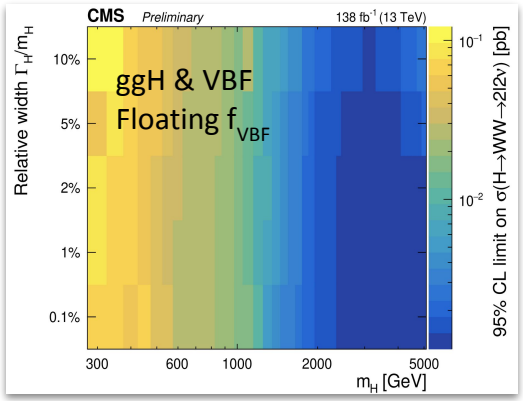
Searches for non-SM Higgs (+ more in backup)

High-mass H → WW (2ℓ) via ggH and VBF

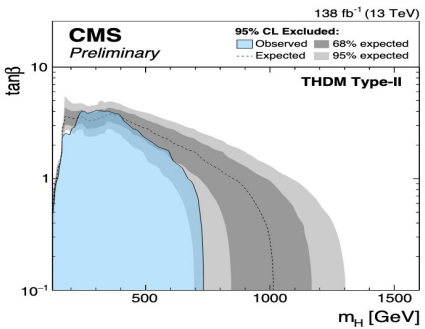
Signal - background interference considered

Largest excess @ 650 GeV
2.6σ global (3.8σ local)

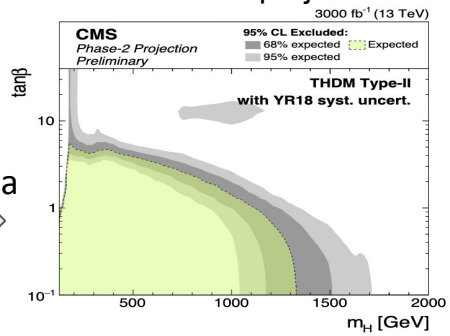




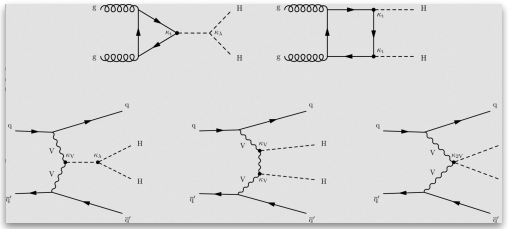
Various interpretations in MSSM and 2HDM + Phase-2 projections

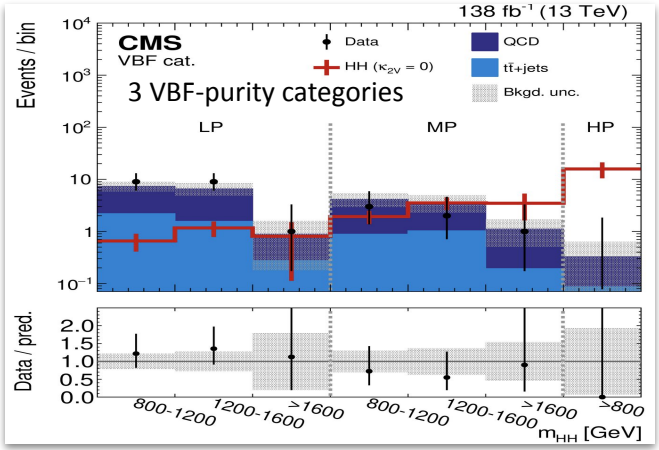


x20 data



Boosted non-resonant Higgs pair production
(4b, using a graph NN) B2G-22-003 (submitted to PRL)



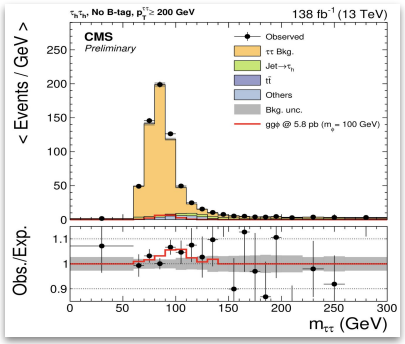


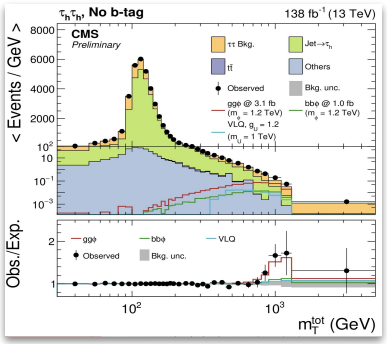
H self-coupling vs. VVHH coupling: (0,0) excluded at 6.3σ

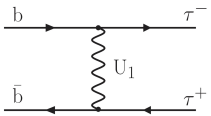
ggH: gluon-gluon fusion Higgs production, VBF: vector boson fusion, MSSM: Minimal Supersymmetric SM, 2HDM: Two Higgs Doublet Model, NN: neural network

Searches for exotic phenomena (+ more in backup)

Resonant [ggφ, φb(b)] & non-resonant [t-channel VLQ] $\tau^+\tau^-$

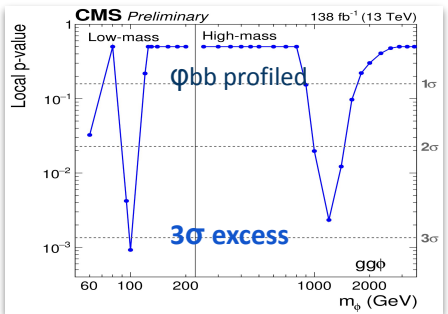




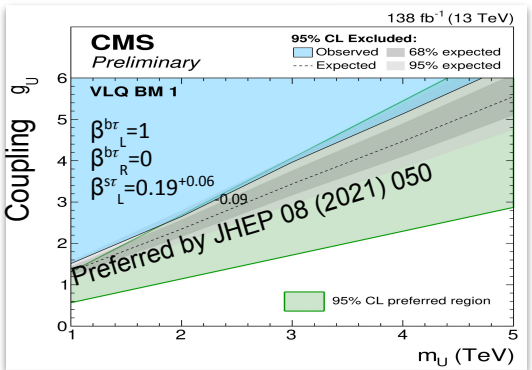


Possible destructive interference for vector-like LQ production

HIG-21-001



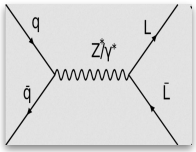
consistent across final states & years

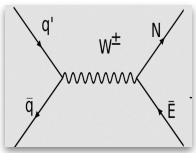


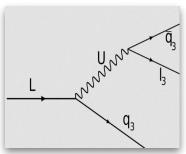
Vector-like leptons (≥3b+ττ/τν/νν)

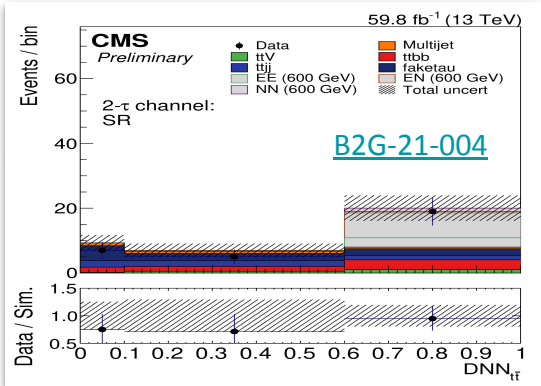
SU(4)×SU(3)×SU(2)*L*×U(1)'

UV-complete model to explain B anomalies





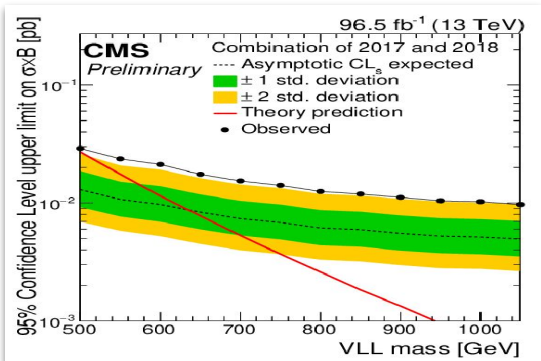




Excess:

2.8σ

@600 GeV

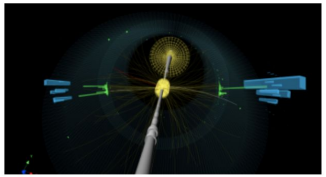


Model-independent, MSSM H/A & VLQ interpretations

VLQ motivated by B-physics anomalies, e.g., lepton flavour (non-)universality in NC & CC B decays

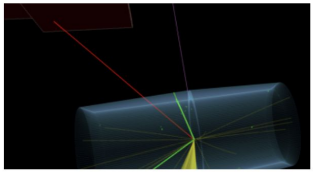
ggφ: gluon-gluon fusion scalar production, VLQ: vector leptoquark, NC / CC: neutral / charge current, UV: ultraviolet

Physics communications



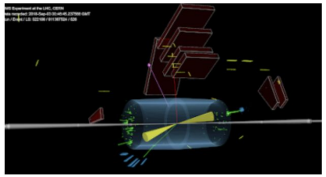
W, Z, AND HIGGS BOSONS AS PORTALS TO EXOTIC PHYSICS

13 MAY 2022



SEARCH FOR DOUBLE HIGGS PRODUCTION WITH MULTIPLE LEPTONS

10 MAY 2022

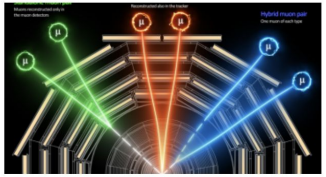


SEARCH FOR RARE PRODUCTION OF VECTOR BOSON PAIRS

06 MAY 2022

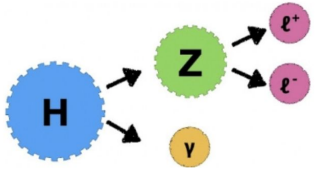
PAY ATTENTION: CMS MAGNET POWERED ON!

15 MAR 2022 |



IN A DETECTOR FAR, FAR AWAY: SEARCHING FOR ELUSIVE LONG-LIVED TRAVELLERS BY TRACING PAIRS OF MUONS

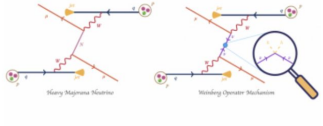
02 MAY 2022



A POSSIBLE NEW DECAY MODE OF THE HIGGS BOSON

28 APR 2022

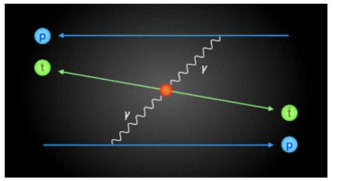
It has been almost a decade since the Higgs



TWO ENDS OF A SEESAW 25 APR 2022

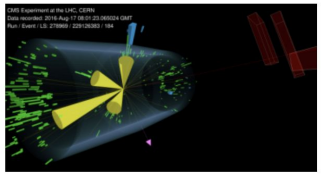
Neutrinos (ν) are the most intriguing particles in nature. The evolution in our understanding about the characteristics of the neutrinos is

11 briefings since March LHCC



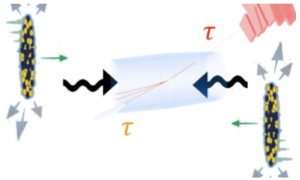
DETECTING THE CREATION OF TOP QUARKS OUT OF LIGHT

19 APR 2022



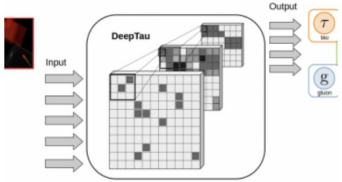
CMS COLLABORATION MEASURES THE MASS OF THE TOP QUARK WITH UNPARALLELED ACCURACY

13 APR 2022



USING LIGHT TO MAKE COUSINS OF THE ELECTRON

07 APR 2022



DEEP LEARNING TECHNIQUE IDENTIFIES COMPLEX DECAYS OF TAU LEPTONS

15 MAR 2022

CERN COURIER | Reporting on international high-energy physics

Physics ▾ | Technology ▾ | Community ▾ | In focus | Magazine

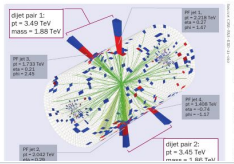
SEARCHES FOR NEW PHYSICS | NEWS

CMS

Dijet excess intrigues at CMS

The Standard Model (SM) has been extremely successful in describing the behaviour of elementary particles. Nevertheless, conundrums such as the nature of dark matter and the cosmological matter–antimatter asymmetry strongly suggest that the theory is incomplete. Hence, the SM is widely viewed as an effective low-energy limit of a more fundamental underlying theory that must be modified to describe particles and their interactions at higher energies.

A powerful way to discover new particles expected from physics beyond



jets by a candidate event recorded in 2017, which was presented by a previous CMS search for dijet resonances (figure 1). This spectacular event has four high-transverse-momentum jets forming two dijet pairs, each with an invariant mass of 1.9 TeV and a four-jet invariant mass of 8 TeV.

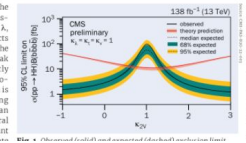
The CMS collaboration recently found another very similar event in a new search optimised for this specific Y → XX → four-jet topology. These events could originate from quantum-chromodynamics processes, but those are expected to be extremely rare (figure

ENERGY FRONTIERS

CMS

Graph neural networks boost di-Higgs search

Two fundamental characteristics of the Higgs boson (H) that have yet to be measured precisely are its self-coupling λ, which indicates how strongly it interacts with itself, and its quartic coupling to the vector bosons, which mediate the weak force. These couplings can be directly accessed at the LHC by studying the production of Higgs-boson pairs, which is an extremely rare process occurring about 1000 times less frequently than single-H production. However, several new-physics models predict a significant



efficiency of 60%, ParticleNet rejects background jets twice as efficiently as the previous best algorithm (an earlier iteration of ParticleNet). A modified version of this algorithm is also used to improve the H–jet mass resolution by nearly 40%.

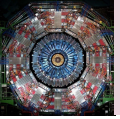
Using the full LHC Run-2 dataset, the new result excludes an HH production rate larger than 8.8 times the SM cross-section at 95% confidence level, versus an expected limit of 4.8. This represents an improvement by a factor of 30 compared to the previous best

We are ready for Run 3 & eagerly waiting for physics at 13.6 TeV !

CMS Experiment at the LHC, CERN
Data recorded: 2022-May-27 08:01:41.164608 GMT
Run / Event / LS: 352417 / 11479080 / 12

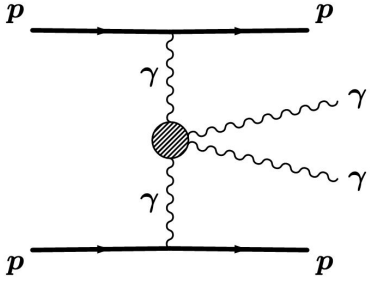
Thank you, LHC!

900 GeV collision in 2022 May



Extra

Exclusive diphoton production with tagged protons



Fiducial volume:

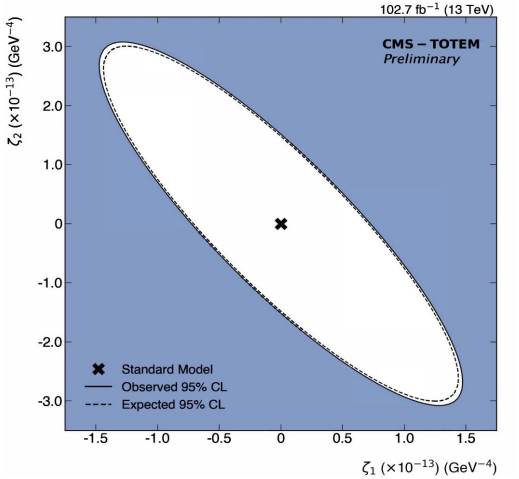
$p_T{}^{\gamma} > 100$ GeV

$0.035 < \xi_{PPS} < 0.15\ (0.18)$

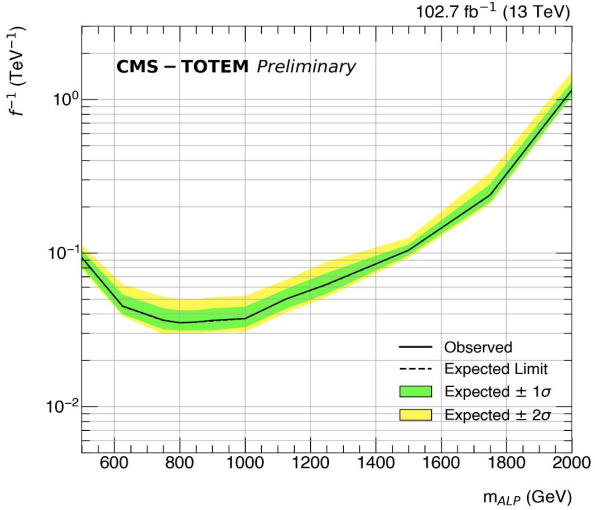
EXO-21-007

Dim-8 anomalous 4-photon coupling

$$\mathcal{L}_{4\gamma} = \zeta_1 F_{\mu\nu}F^{\mu\nu}F_{\rho\sigma}F^{\rho\sigma} + \zeta_2 F_{\mu\nu}F^{\nu\rho}F_{\rho\lambda}F^{\lambda\mu}$$



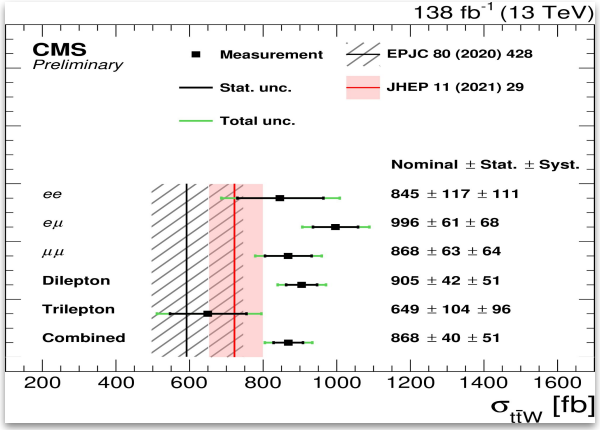
Strongest limits on axion-like particle on coupling - mass plane in fiducial volume

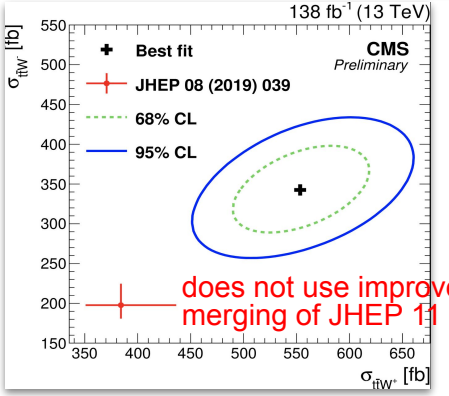


Top cross-section measurements

ttW production (2ℓ/3ℓ) TOP-21-011

2σ tension with old NLO+NLL calculation





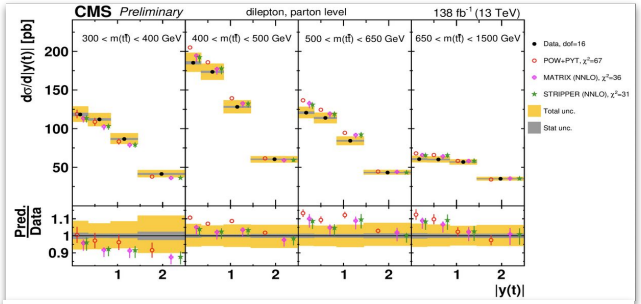
does not use improved FxFx ME merging of JHEP 11 (2021) 29

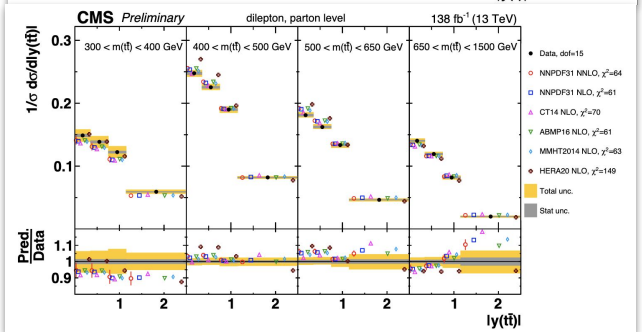
tt+jet (OS 2ℓ) 1D/2D/3D TOP-20-006

fiducial / full-phase-space diff. xsec. @ particle / parton levels

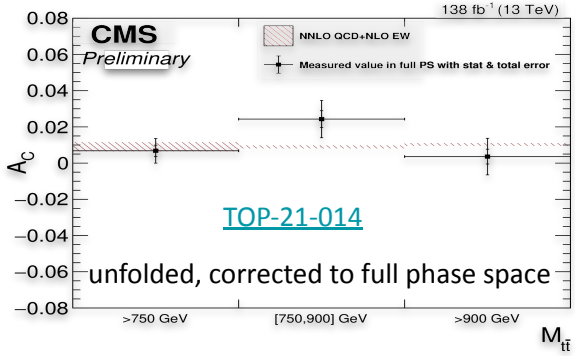
Compared to NLO MC & beyond NLO theory: softer top p_T, less central

Largest differences for multi-D xsec

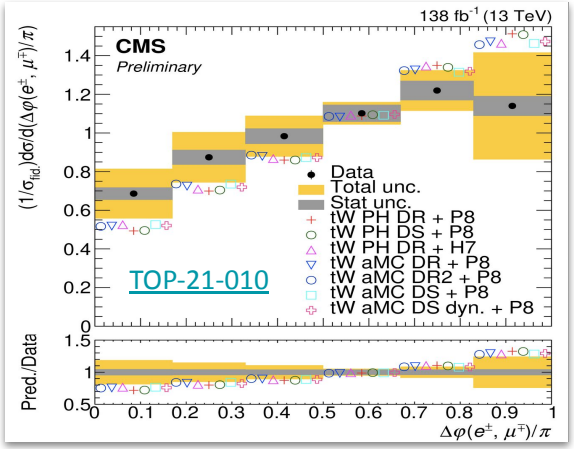




tt charge asymmetry (boosted ℓ+jets)



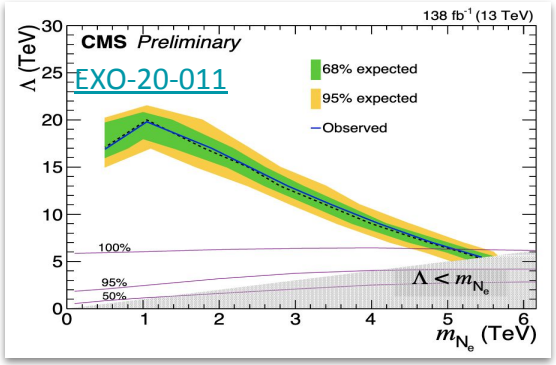
tW inclusive & fiducial differential

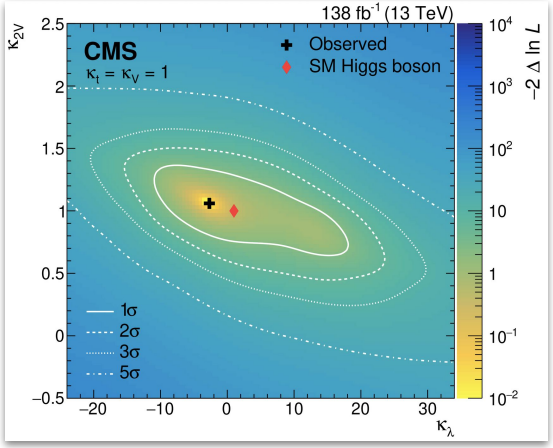


More searches…

Heavy composite majorana neutrinos

interpret $\sigma(pp \to \ell N_\ell) \times \mathcal{B}(N_\ell \to \ell q\bar{q}')$



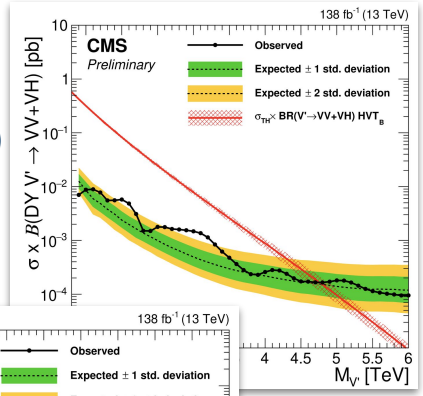


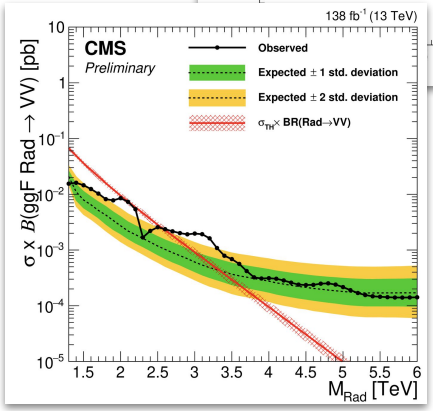
Boosted heavy diboson (WW, WZ, ZZ, WH, ZH) resonances

2 large-R jets (+ 2 VBF), ML W/Z/H tag

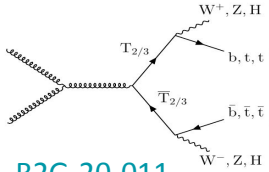
B2G-20-009

Largest excess: 3.6σ (2.3σ global) @ 2.1 TeV & 2.9 TeV

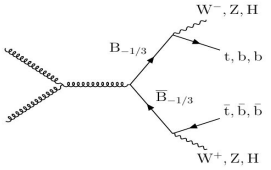




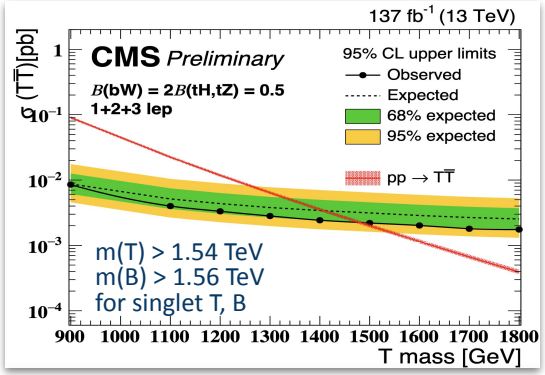
Vector-like TT and BB quark



B2G-20-011



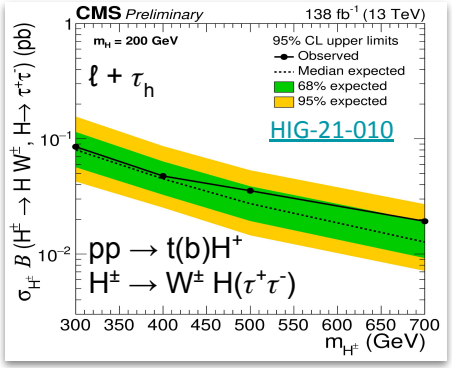
- 1ℓ + MET + 3 boosted large-R jets, DNN W/Z/H/t/b/q-tag
- $\ell^\pm\ell^\pm$ or ≥3ℓ with large p_T
- Strongest TT (all modes) & BB (for B⟶tW) limits

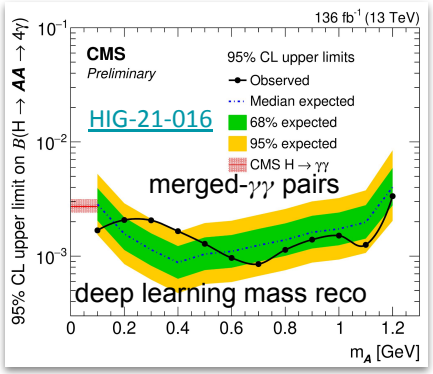


6.1 fb (2016), 3.1 fb (120 fb^{-1} projection) ⟶ 2.5 fb (expected) @ 1.8 TeV

More searches…

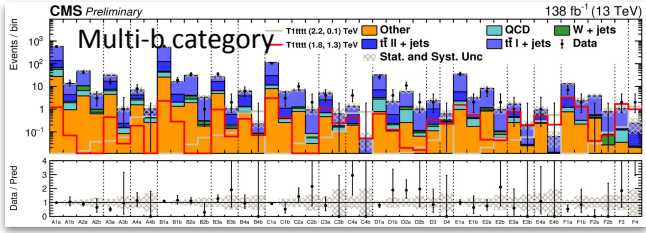
Extended Higgs sector

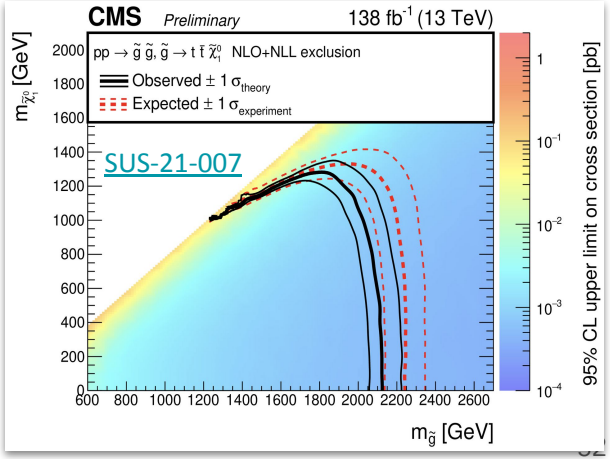




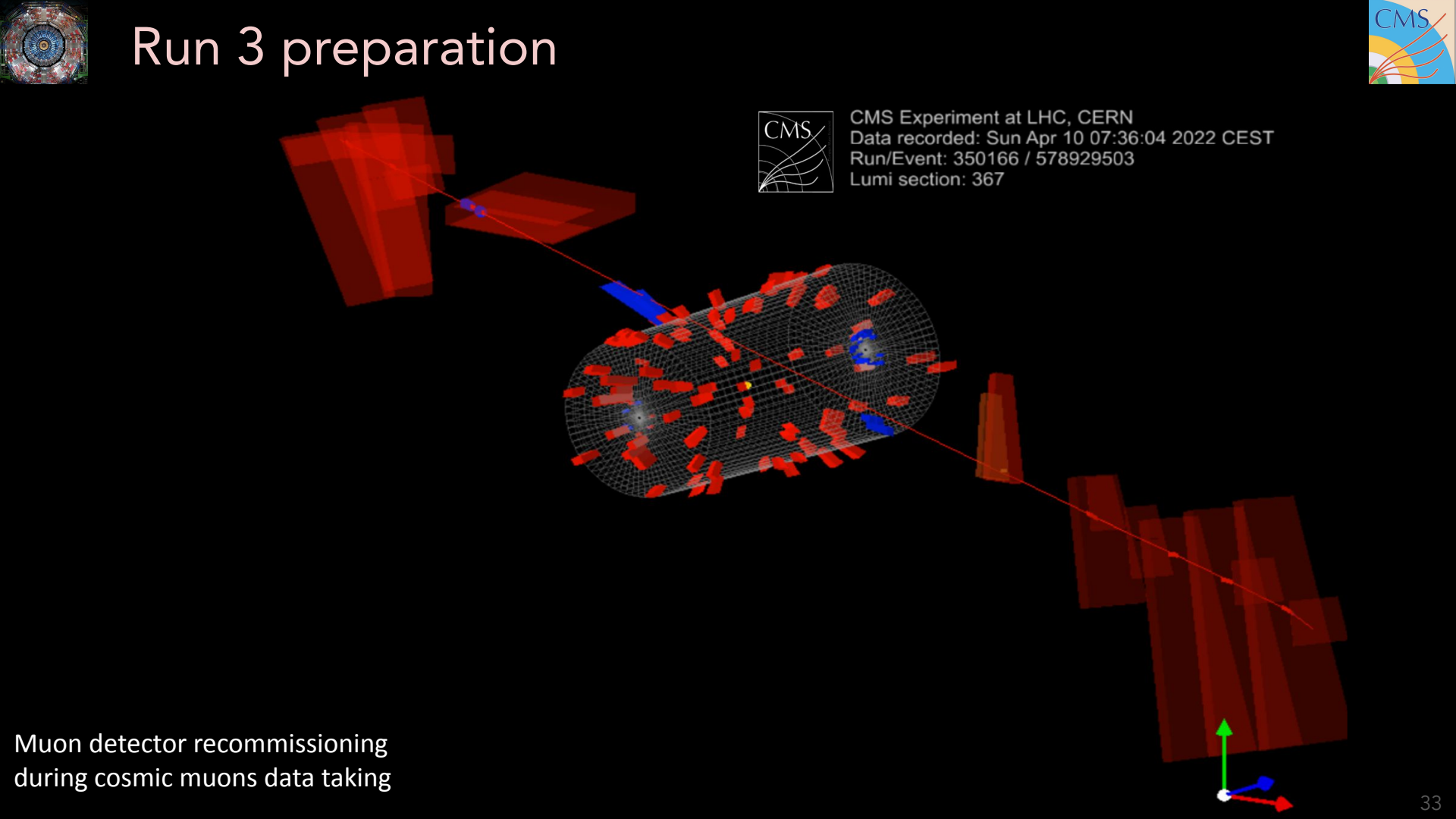
SUSY gluino pairs with 1 lepton

($\Delta\phi = \sphericalangle(\vec{p}_{\mathrm{T}}^{\,\ell}, \vec{p}_{\mathrm{T}}^{\,\mathrm{W}})$, ML b/t/W-tag)



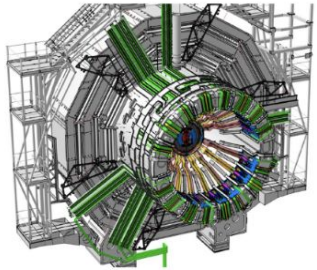


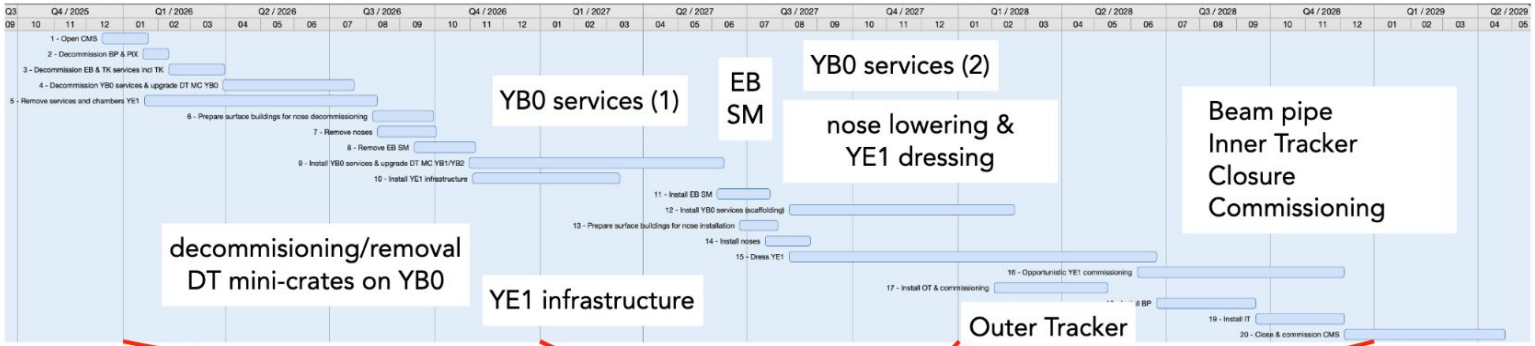
Run 3 preparation



Muon detector recommissioning
during cosmic muons data taking

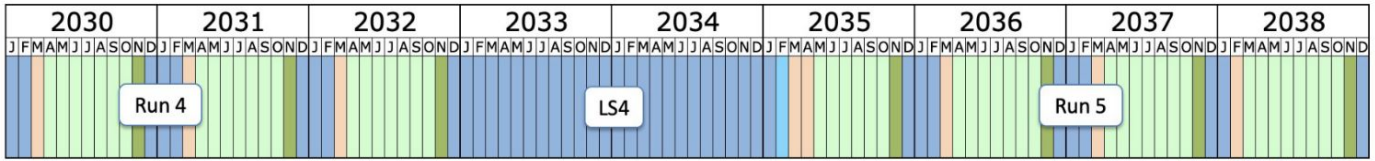
Phase-2 and LS3 planning





Longer term LHC schedule

In January 2022, the schedule was updated with long shutdown 3 (LS3) to start in 2026 and to last for 3 years.



Last updated: January 2022

Shutdown/Technical stop
Protons physics
Ions
Commissioning with beam
Hardware commissioning/magnet training

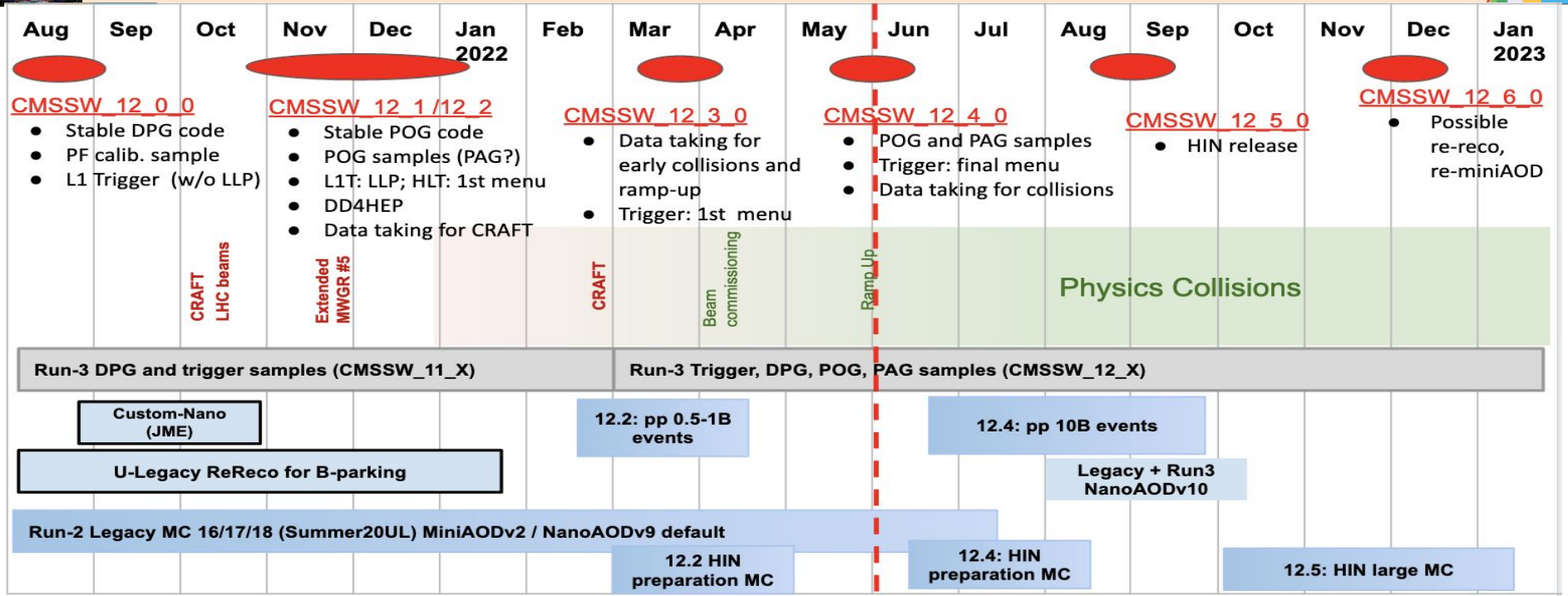
LS3
- start: 2026
- length: 3 years

Run4
- start: 2029
- length: 4 years

LS4?
- start: 2033
- length: 2 years

Work on-going
- contingencies
- risk mitigation

Release and production plan: on schedule



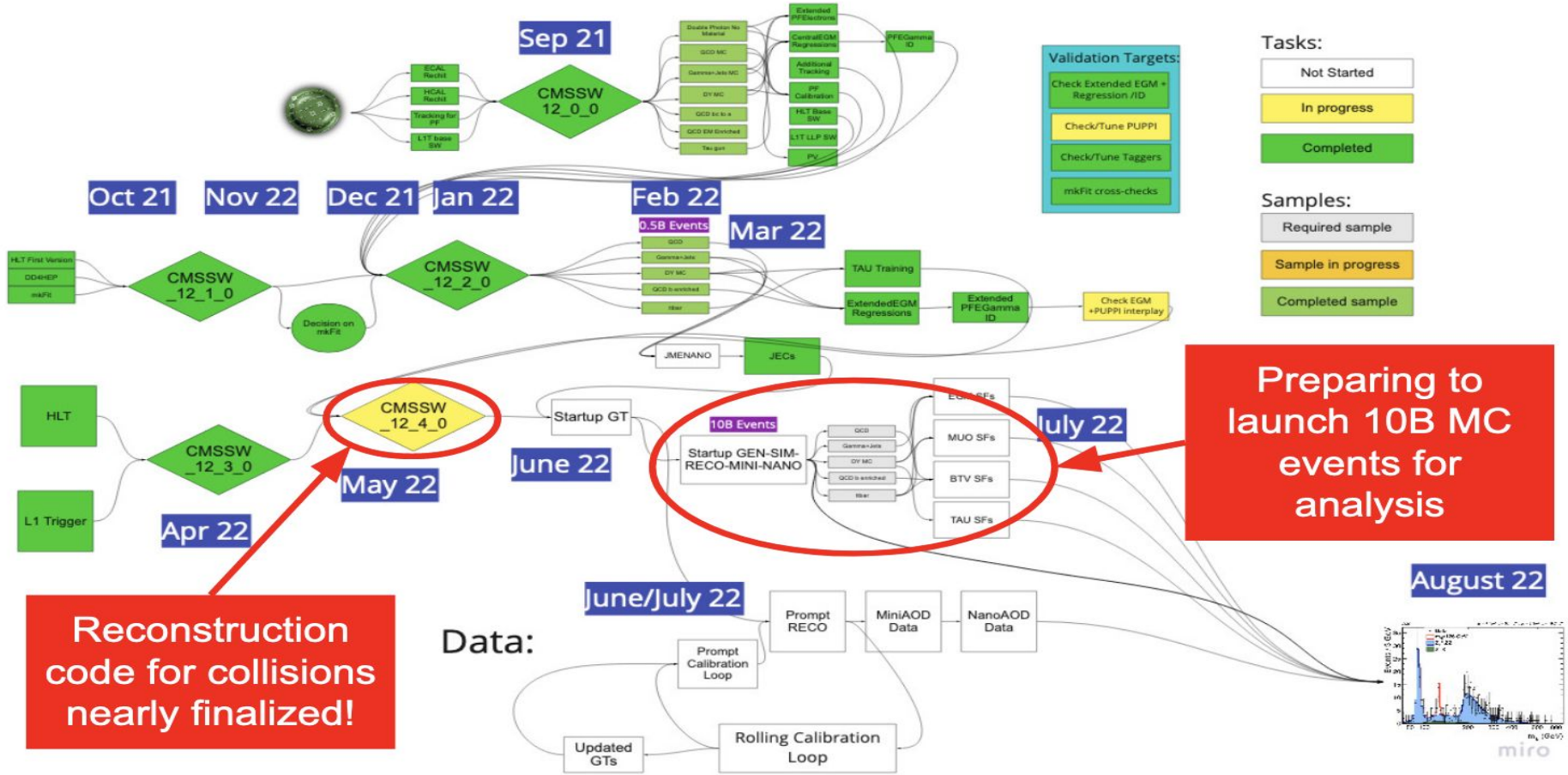
Run-2 Legacy
- Produced ~60 Billion MC events in 2021
- Re-NanoAOD (target every few months)
- Custom-NanoAOD: establish for JME
- Re-MiniAODv2 (and v3)
- High-precision calibration and SF
- Re-reco of B-parking in 10_6

Run-3 Preparation
- GPU and Scouting
- Detectors, conditions and trigger
- Skims
- Code freeze and calibrations
- Analysis preparation

Phase-2 Preparation
- Snowmass
- Regular high-stats samples (500k events) within the RelVal framework

Updated on 21 January 2022 XC meeting

Run 3 physics analysis object flowchart



Alma Linux 8 for Run 3

- Alma Linux: free and 1:1 compatible with Red Hat Enterprise Linux (RHEL) - a RHEL *clone*
  - Can be used on the Grid for our containers
  - Compatible with Centos Stream 8 too
  - End of life: 2029
- CMS successfully validated physics results CMSSW+Alma
  - Alma is the default for all new releases
- Identical OS at the HLT and on the Grid
  - Minimize maintenance effort: identical OS and same software online and offline
- New OS crucial to support latest hardware architectures, e.g. accelerators
  - Instrumental to exploit next generation facilities

AlmaLinux
https://almalinux.org

General CUDA

- CentOS Linux 8 has reached End-of-Life on December 31, 2021. Support for this OS is now removed from the CUDA Toolkit and is replaced by Rocky Linux 8.

From CUDA 11.6 Release Notes

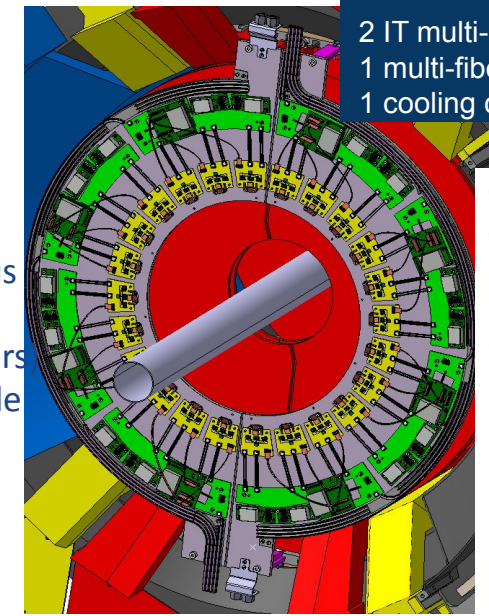
CMS chose Alma Linux 8 for Run 3

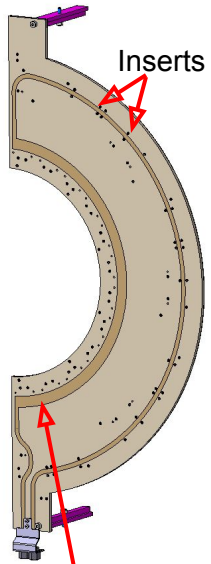
Fast Beam Condition Monitor evolution since TDR

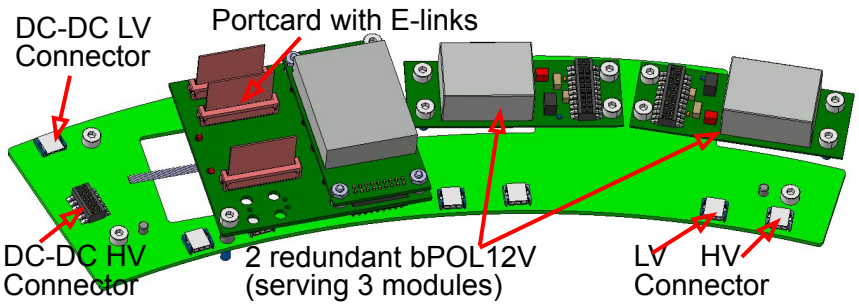
- ASIC: 6 channels, optimised for fast time response & low noise at the expense of power
- Electronics system design
  - Control & read out via Inner Tracker (IT) portcards: 3 lpGBT + 3 VTRx+
  - Powering via 2 redundant bPOL12V
- Modular system design with identical components everywhere
  - Single-chip modules with 3 double-pad diodes (baseline)
  - Thermally optimised design: AlN base + flex-rigid hybrid
  - 1 service board / 3 FE modules (power, control, read out) at higher radius
- Mechanics follows IT design (materials & manufacturing, vendors)
  - Minor modifications: cooling in specific regions (sensors, DCDC converters
  - Studying different disk cross sections as cooling only required on one side
- Currently working on finalising services and integration
  - Dedicated FBCM connection region on PP0
  - Connecting to TEPX1 cooling manifolds for redundancy with D4R1 (simulations & optimisation launched)

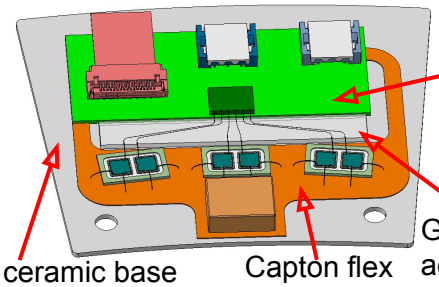
2 identical half-disks with 12 modules per end of CMS (+/-z)

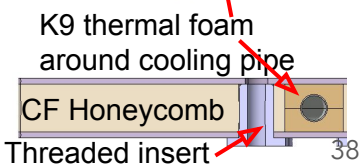
2 IT multi-service cables, 1 multi-fiber bundle & 1 cooling capillary







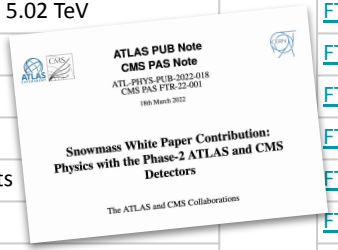




List of new analyses since last LHCC

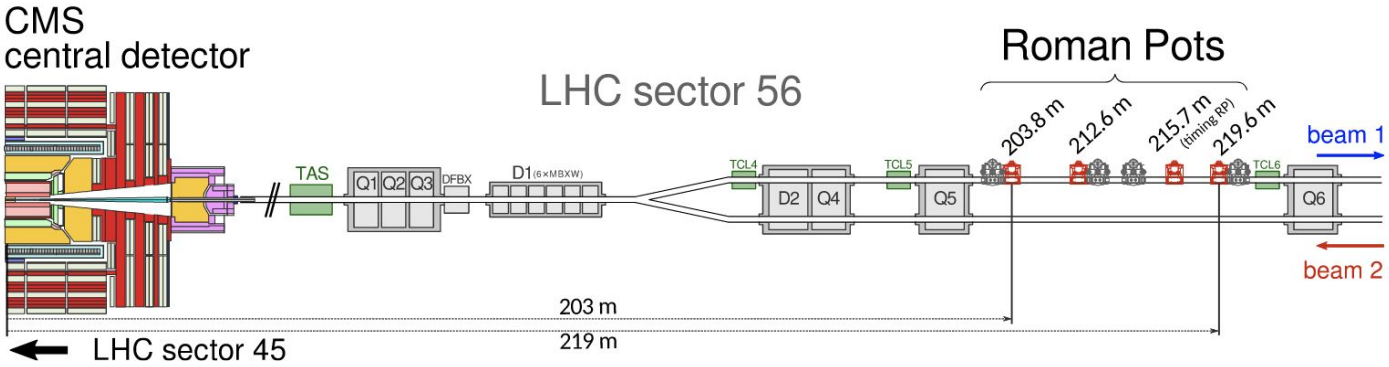
Link	Title
EXO-19-009	Search for anomalous Z(ll)+X and gamma+X production with PPS
HIG-19-016	SM H -> gg differential and fiducial cross sections (full run 2)
EXO-20-011	Search for heavy composite Majorana neutrino
B2G-20-011	Search for VLQ pair production in leptonic final states with Run 2 data
HIN-20-003	Measurement of inclusive b jet shapes in PbPb collisions at 5.02 TeV
HIG-20-016	High Mass H -> WW with full Run2
TOP-20-008	Top mass measurement with a new profile likelihood method
HIG-21-001	MSSM H/A -> tau tau search with full Run-2 data
HIN-21-001	Measurement of azimuthal anisotropy for Y(1S) meson in pPb collision at 8.16 TeV
HIN-21-002	Jet v2 and v3 from dijet events in PbPb collisions at 5.02 TeV
EXO-21-007	Diphoton production with two protons in CT-PPS
HIN-21-003	Azimuthal anisotropy of non-prompt D0 meson in PbPb collisions at 5.02 TeV
HIG-21-010	Search for Charged Higgs in WH decays (H+ -> W+H)
HIG-21-012	Search for ggH, H -> cc
TOP-21-008	Top quark pole mass extracted from tt+j
TOP-21-010	Inclusive and differential measurements of tW with dileptonic events
HIG-21-015	Search for H -> ee
TOP-21-011	Measurement of the inclusive ttW cross section with full Run 2 dataset
TOP-21-012	Measurement of the Jet Mass Distribution in Boosted Top Quark Decays with Run 2 Data
SUS-21-007	Search for SUSY in 1L final states with the deltaPhi variable (Run2 legacy)
SMP-21-011	EW Wgamma plus 2 jets at 13 TeV full run 2
HIG-21-016	H -> aa -> 4photons boosted (very low mass)

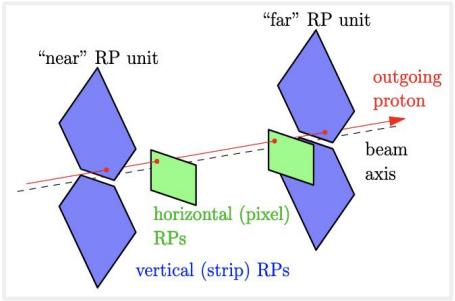
Link	Title
HIN-21-007	Excited bottomonium states measurement in PbPb collisions at 5.02TeV
TOP-21-014	Charge asymmetry in boosted top quark pairs (lepton + jets)
HIN-21-008	Measurements of the azimuthal anisotropy of charmonia in PbPb collisions at sqrt(sNN) = 5.02 TeV
HIN-21-010	The v2{2k}(k=1,...,5) cumulants and hydrodynamics probes in 5.02 TeV PbPb collisions
HIN-21-011	Measurement and analysis of two-particle HBT correlations and their Levy parameters in 5.02 TeV PbPb collisions
HIN-21-012	Correlations between multiparticle cumulants and mean transverse momentum in small collisions with the CMS detector
B2G-21-004	Search for pair-produced vector-like leptons in ≥ 3b + N τ final states


ATLAS PUB Note
CMS PAS Note
ATL-PHYS-PUB-2022-018
CMS PAS FTR-22-001
18th March 2022
Snowmass White Paper Contribution: Physics with the Phase-2 ATLAS and CMS Detectors
The ATLAS and CMS Collaborations

Link	Title (for Snowmass)
FTR-18-034	Projections of Top Quark Spin Correlations to 14 TeV and 3 ab-1
FTR-21-003	HH to WWgammagamma
FTR-21-006	Higgs to two muons at the HL-LHC
FTR-21-007	H -> 4l mass and width measurement
FTR-21-008	H -> gamma gamma mass and width measurements
FTR-21-009	Search for Rare Higgs Decays with Mesons
FTR-21-010	Nonresonant ttHH search
FTR-21-011	SUSY Z' to ll + MET
FTR-22-003	Seesaw Model Searches Using Multilepton Final States
FTR-22-005	H to bb + MET at the HL-LHC
FTR-22-006	Doubly charged Higgs in 4 leptons final states

Precision Proton Spectrometer



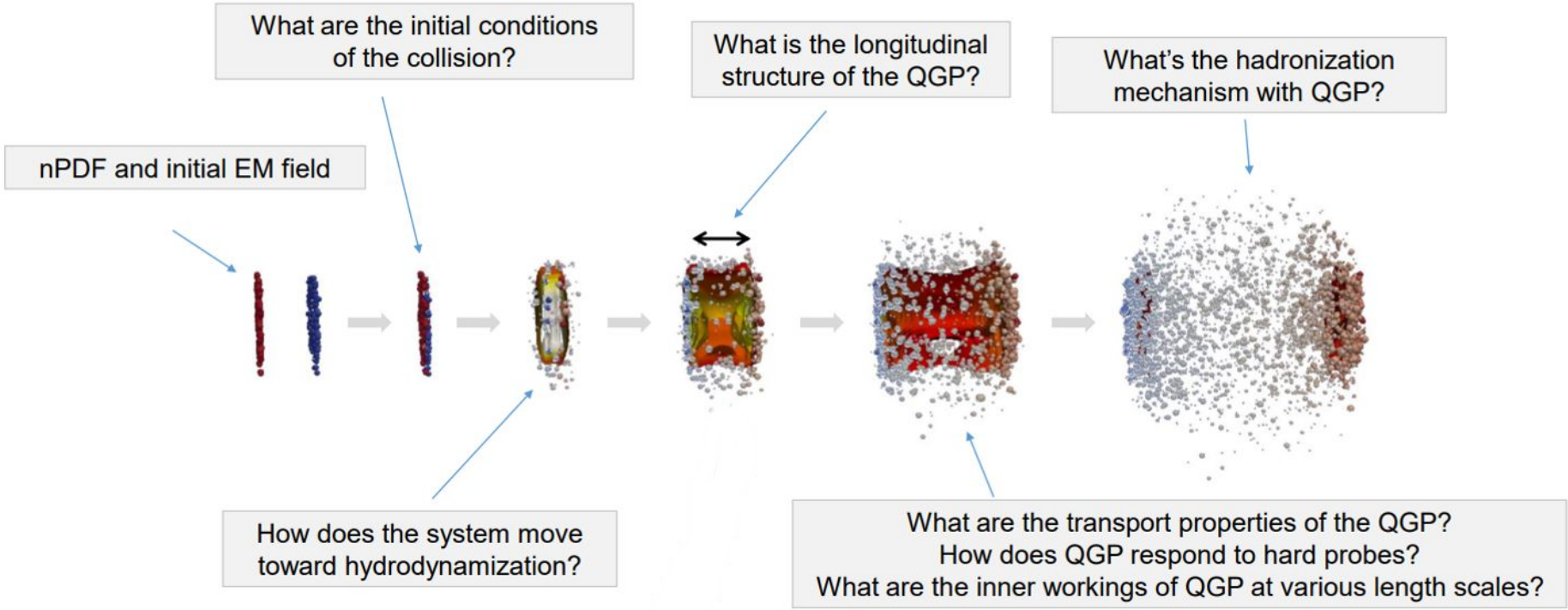


$$\xi = (p_{\mathrm{nom}} - p)/p_{\mathrm{nom}}$$

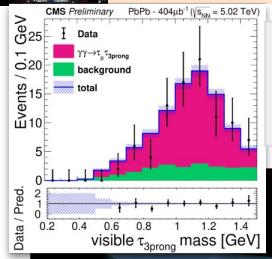
$$m_{pp} = \sqrt{s\xi_p^+\xi_p^-},$$

$$y_{pp} = \frac{1}{2}\log\left(\frac{\xi_p^+}{\xi_p^-}\right)$$

Pinning down the Standard Model of Heavy Ion collisions



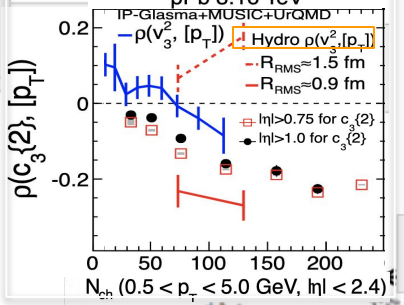
Pinning down the Standard Model of Heavy Ion collisions

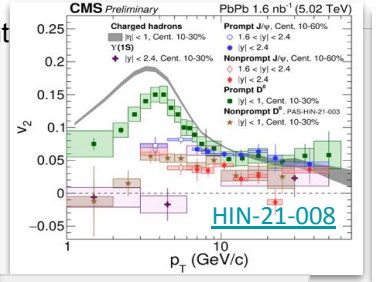


Initial state & flow with higher-order cumulants

HIN-21-012

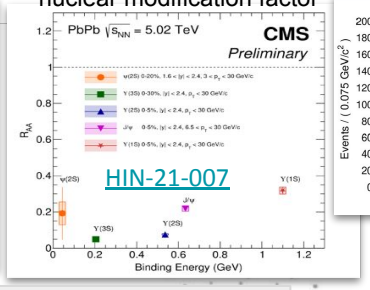
correlator using 2-particle cumulant



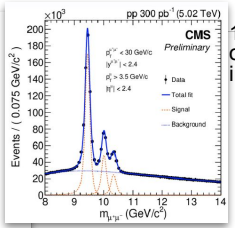


HIN-21-008

nuclear modification factor



HIN-21-007



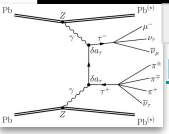
1st Υ(3S) observation in PbPb

CMS FIRST measured

Many new results at QM2022 and other conferences!

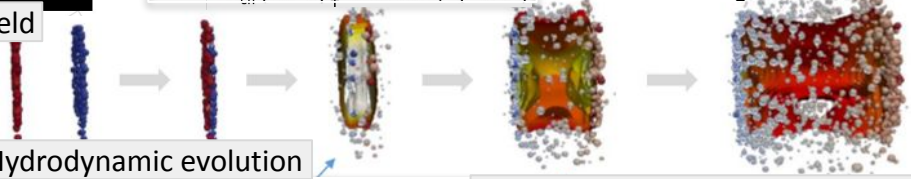
Azimuthal anisotropy: improved HF v_2

Sequential suppression



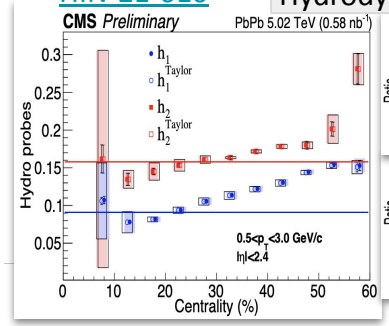
Initial EM field

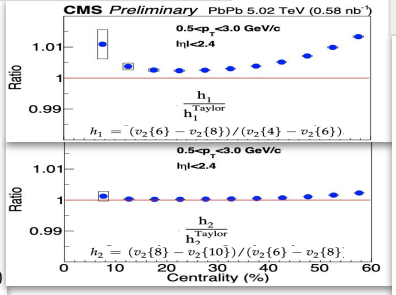
HIN-21-009



Hydrodynamic evolution

HIN-21-010

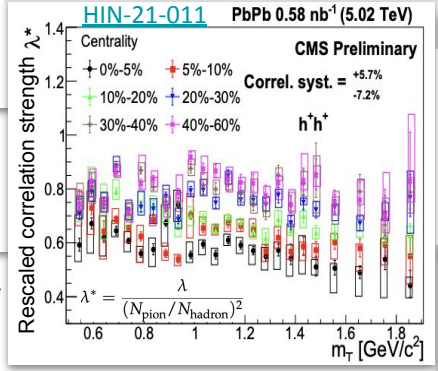




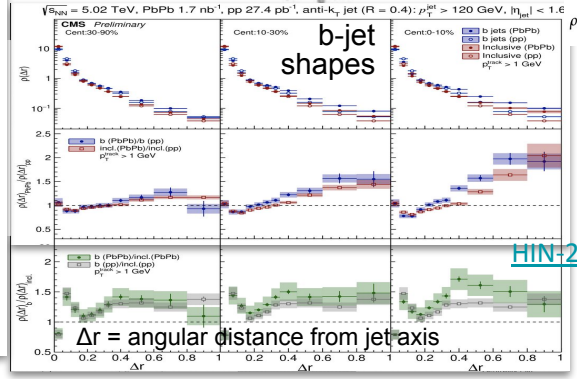
Test initial state geometry assuming hydrodynamic evolution of the medium: interaction region shape evolves with centrality

2-particle BEC & Levy parameters

HIN-21-011



Flavour dependence of jet - medium interactions



$$P(\Delta r) = \frac{1}{\delta r}\frac{1}{N_{\text{jet}}}\Sigma_{\text{jets}}\Sigma_{\text{trk}\in(\Delta r_a,\Delta r_b)}p_{\text{T}}^{\text{trk}}$$

$$\rho(\Delta r) = \frac{P(\Delta r)}{\Sigma_{\text{jets}}\Sigma_{\text{trk}}p_{\text{T}}^{\text{trk}}}$$

HIN-20-003

Higgs physics

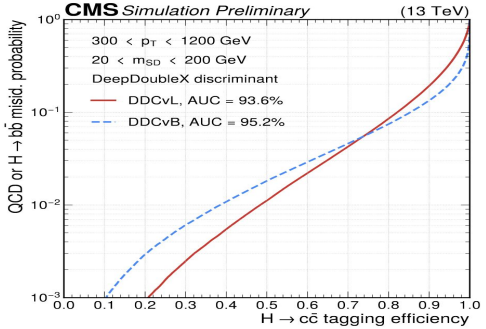
Boosted H → cc search + (Z → cc) + jets observation

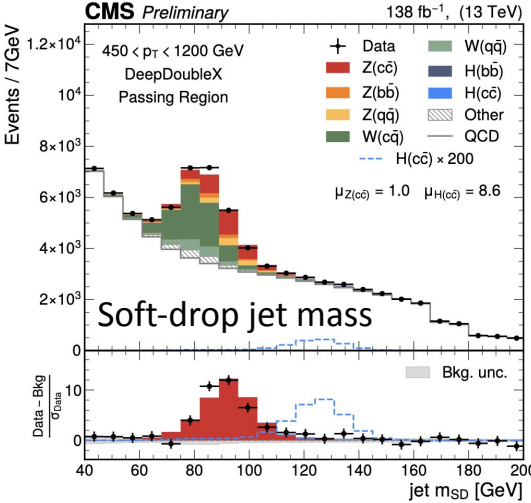
Inclusive in Higgs production mode

$p_T^H > 450$ GeV

Single large-radius jet

Charm-tagged with DNN





(Z → cc) + jets signal strength:

$0.91^{+0.18}_{-0.15}(\text{exp.}) \pm 0.7(\text{th.}) \pm 0.05(\text{stat.})$

H → cc signal strength:
>45 (38) x SM @ 95% CL
(with Z(cc) fixed to SM)

PAS-HIG-21-012