

CMS Status Report

LHCC
17 November 2021

Freya Blekman
on behalf of CMS collaboration
From 1 October 2021: DESY & UniHH



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LHC

Run 3

***THE HUNT FOR NEW PHYSICS
CONTINUES***

Long
shutdown 2
and
preparation
for Run 3

Computing
operations
and
data processing

Physics
Results and
publications

Phase II
upgrades and
the
preparation
for HL-LHC

Long shutdown 2 and Run 3 preparation



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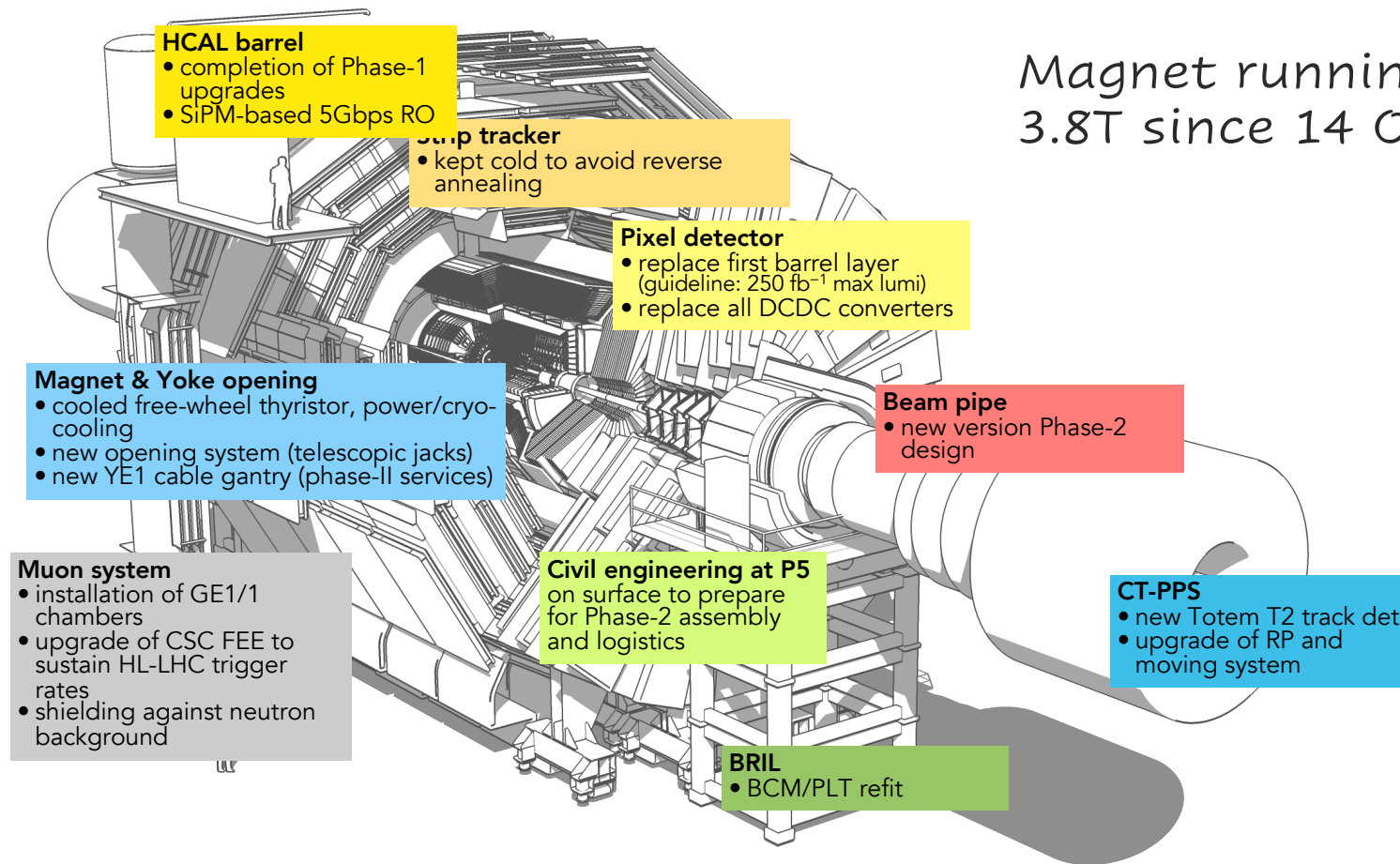


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CMS at end of Long Shutdown 2

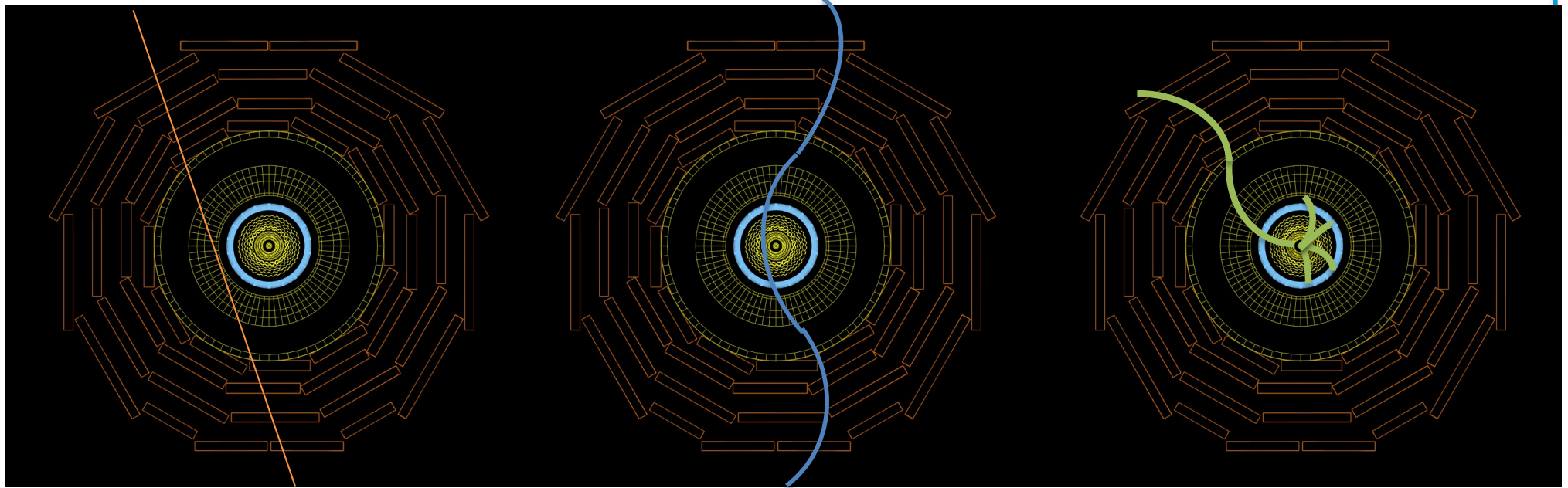
All major LS2 projects are completed

Magnet running at 3.8T since 14 October



Take full advantage of splashes, pilot beams

CMS commissioning: CRUZET/CRAFT/pilot beams



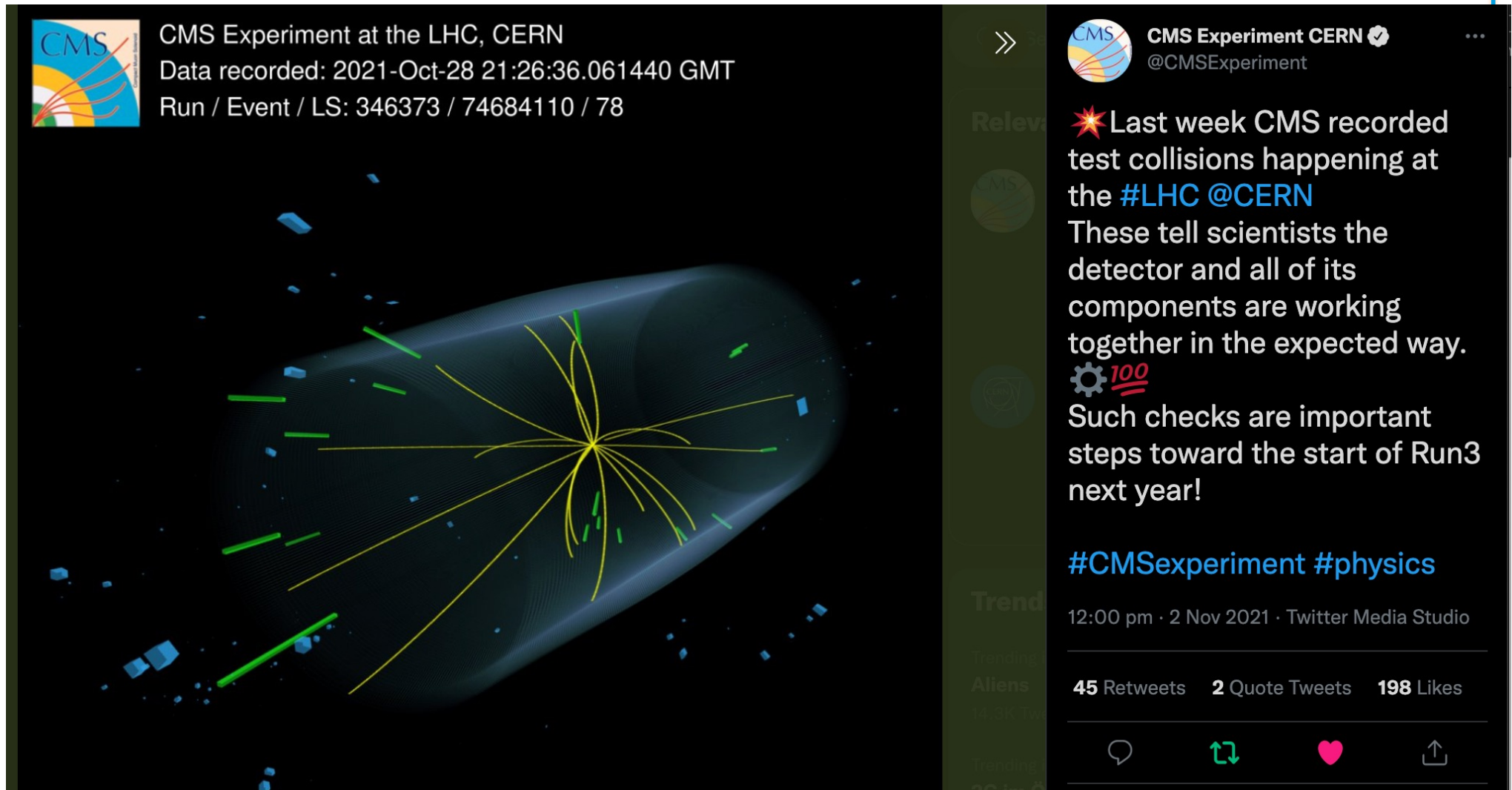
Cosmic **RU**n at
ZEro Tesla

Cosmic **R**un **At**
Four Tesla

splashes, (stable)
pilot beams

All offer opportunities to examine detector, check performance, integration, calibration, timing etc

Global runs extremely useful



The image shows a screenshot of a Twitter post from the CMS Experiment CERN (@CMSExperiment) dated November 2, 2021. The tweet celebrates the recording of test collisions at the LHC, marking a significant step towards the start of Run3 next year. The tweet includes a gear icon with '100' and mentions the hashtags #CMSexperiment and #physics. The engagement statistics show 45 retweets, 2 quote tweets, and 198 likes. To the left of the tweet is a visualization of a particle detector, likely the CMS, showing a central collision point with numerous tracks radiating outwards, colored in yellow and green, against a dark background with blue and green highlights.

CMS Experiment at the LHC, CERN
Data recorded: 2021-Oct-28 21:26:36.061440 GMT
Run / Event / LS: 346373 / 74684110 / 78

CMS Experiment CERN @CMSExperiment

🌟 Last week CMS recorded test collisions happening at the **#LHC @CERN**. These tell scientists the detector and all of its components are working together in the expected way. 🛠️ ¹⁰⁰

Such checks are important steps toward the start of Run3 next year!

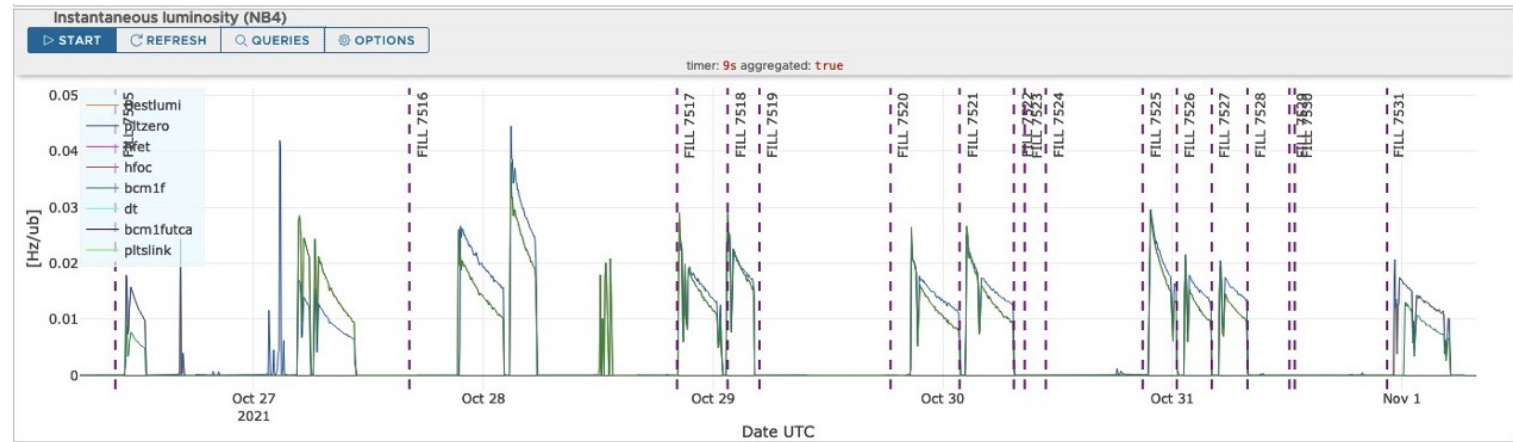
#CMSexperiment #physics

12:00 pm · 2 Nov 2021 · Twitter Media Studio

45 Retweets 2 Quote Tweets 198 Likes

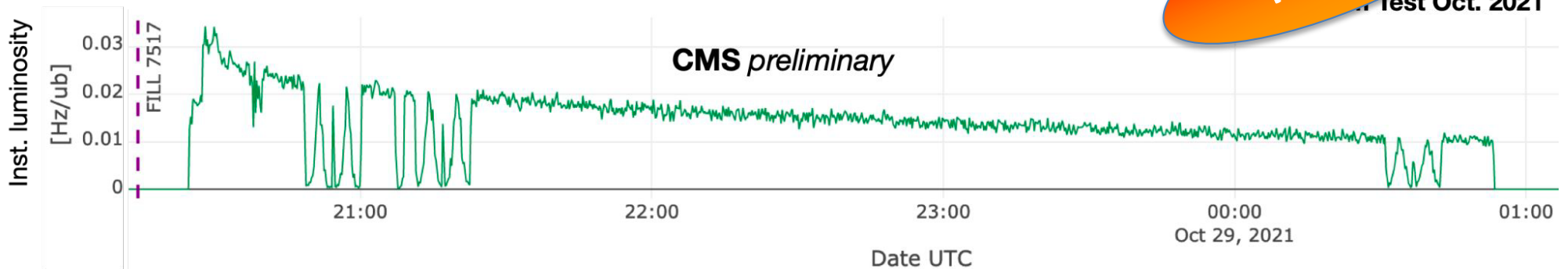


Luminosity during pilot beams



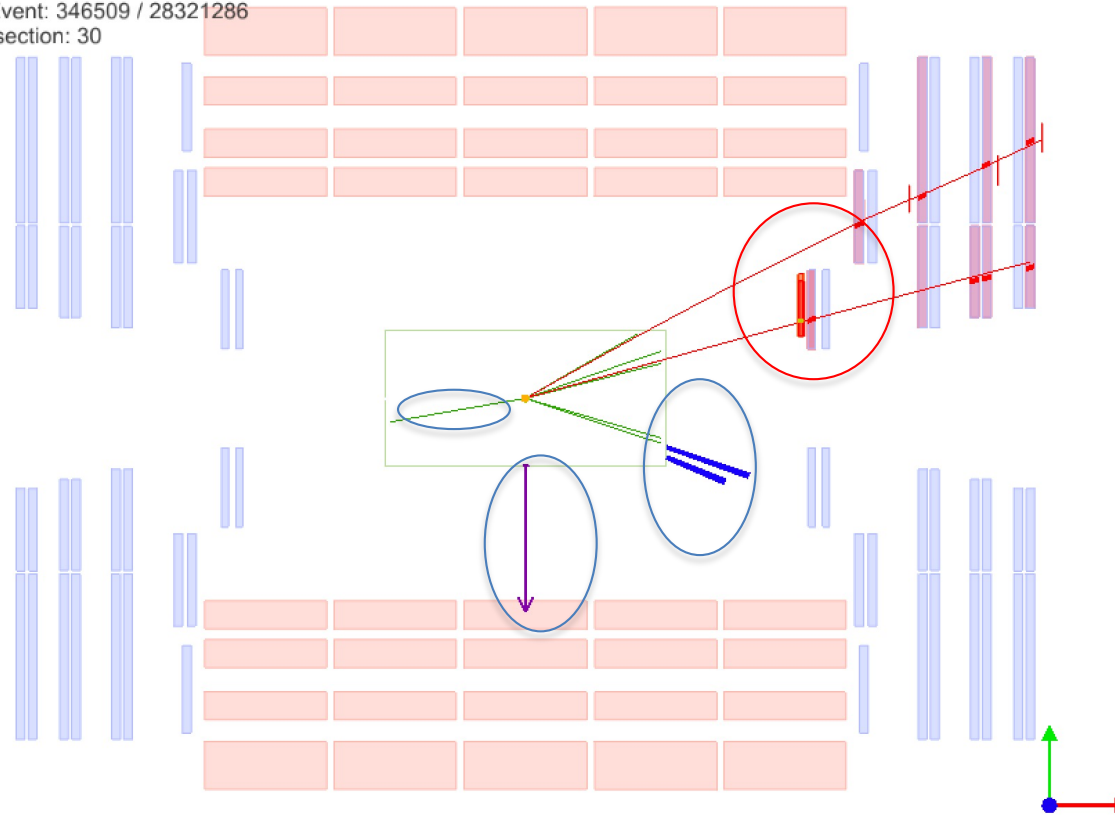
(new) Online luminosity tools working!
And new detector components live essentially 100%

Poster!



GEM detector GE1/1 sees first charmonium in pilot data?

CMS Experiment at LHC, CERN
Data recorded: Mon Nov 1 01:20:45 2021 CET
Run/Event: 346509 / 28321286
Lumi section: 30



Simultaneous operation all of detector

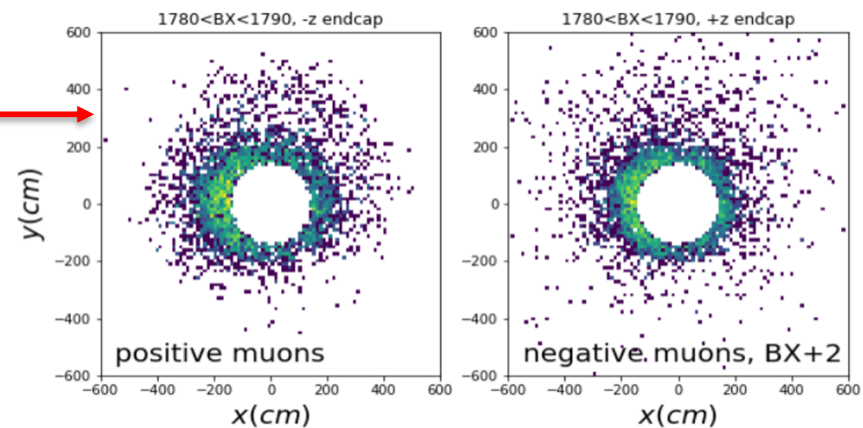
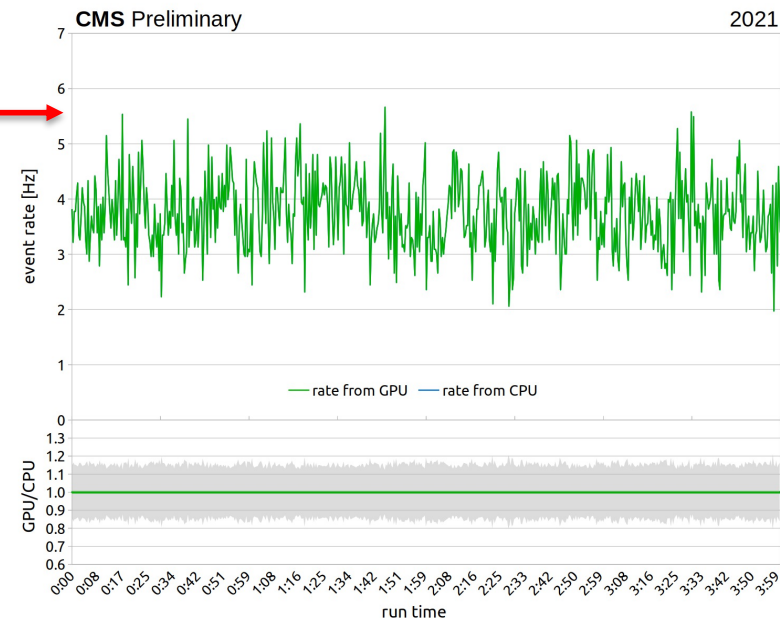
$$m(\mu^+\mu^-) = 3.13 \text{ GeV}/c^2$$



Testing GPUs, triggers and Scouting

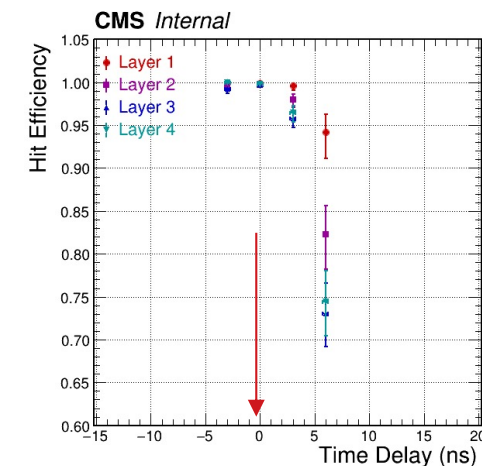
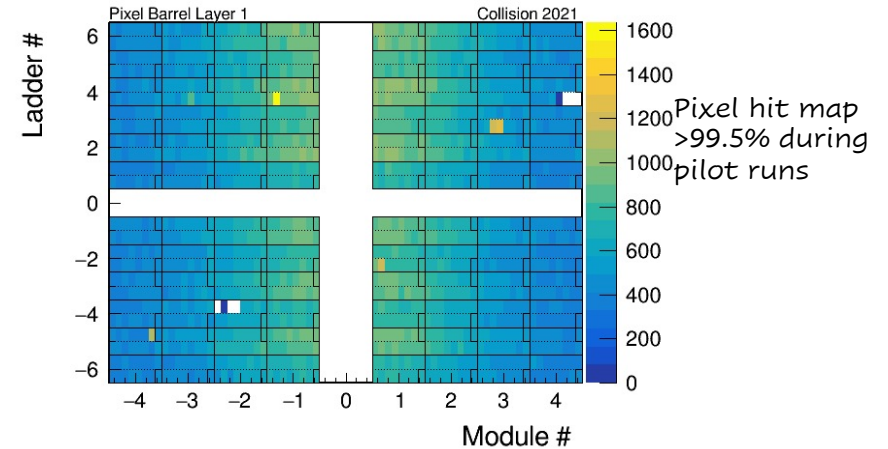
Reminder: costs/benefits with GPUs advantageous!

- Now confirmed GPU vs CPU rates & identical performance in trigger
- Scouting system extended with dedicated FPGAs useable also for inference – stay tuned!
- During beam tests calorimeter scouting can see beam halo muons



Tracker

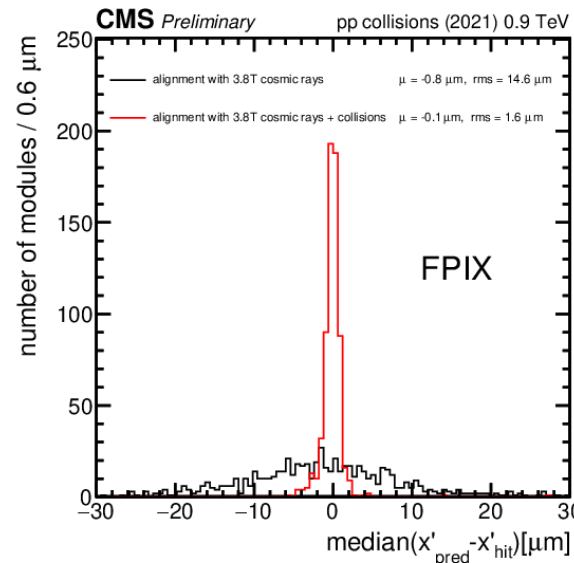
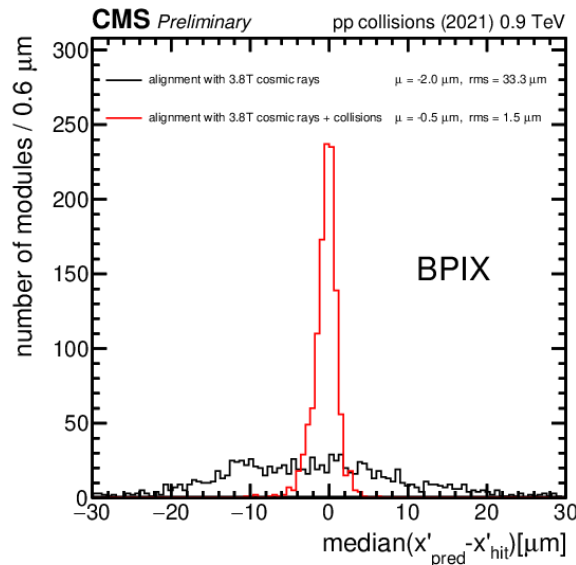
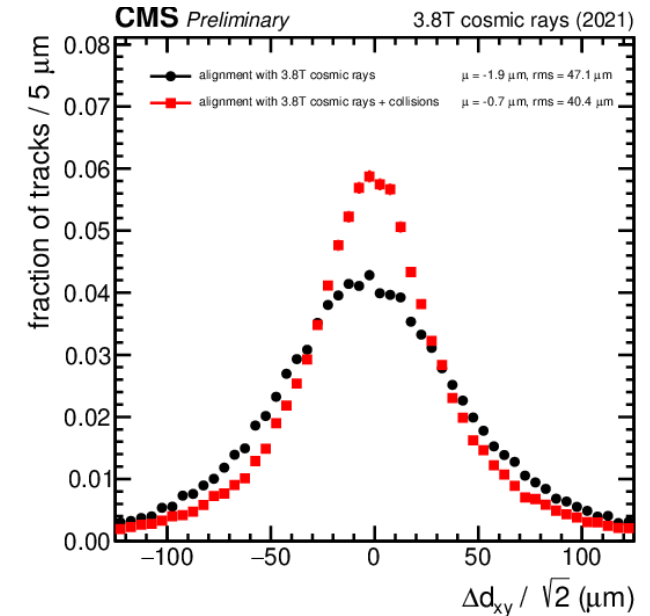
- Pixels
 - Completed commissioning of the refurbished detector and successful data taking during global runs
- Strips
 - Successful data taking in CMS Global Runs
- Pilot Run
 - Both Tracker detectors operated stably throughout the pilot runs



Pixel timing validation, default setting is at 0 ns delay (and looks good!)

Tracker Alignment

- Tracker detectors newly realigned after the insertion of refurbished pixel detector
- Cosmic ray data (black) and LHC pilot beam collisions (red)
- width beam spot (x,y) measured $be \sim 150 \mu\text{m}$
 - And z is in center of CMS!



Poster!

Beam collisions help with accuracy of module position measurements

What would CMS do with an extra month before Run 3?

- Phase II muon detector demonstrators installed
 - More time to commission them
- Open CMS for replacement intermittently defective HCAL barrel readout module
 - non-urgent issue observed during recent global runs
 - fix now instead of during next opportunity/technical stop
- Extended cosmic ray runs (with magnet on) will help us prepare our experiment even better



Computing and data processing

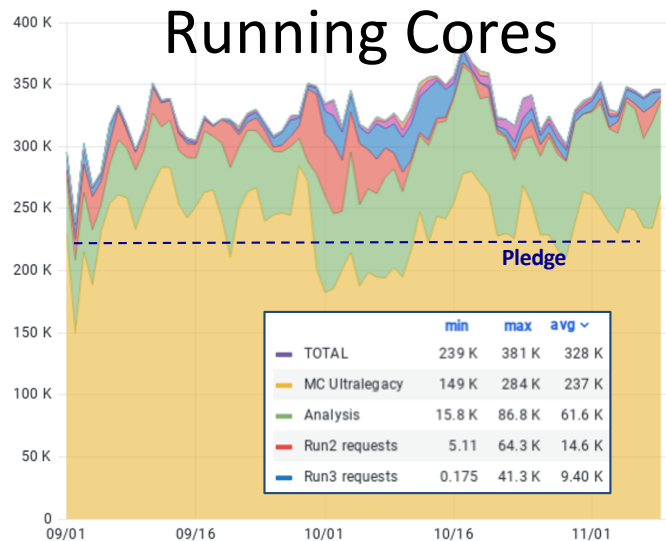


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Computing resources and preparation for Run 3



- **328k CPU cores on average since last LHCC: a record!**
- Level sustained by pledged capacity and opportunistic use of HPC, HLT farm, availability on Tier 1&2s

Legacy reprocessing of 2018 B-Parking sample, 8 PB staged out from tape at CERN

- Learned how to optimize our procedures but also common tools including patches/fixes that benefit LHC community

Run 2 “Legacy” processing data/MC

CMS processed 25 billion data events to 99.96% efficiency

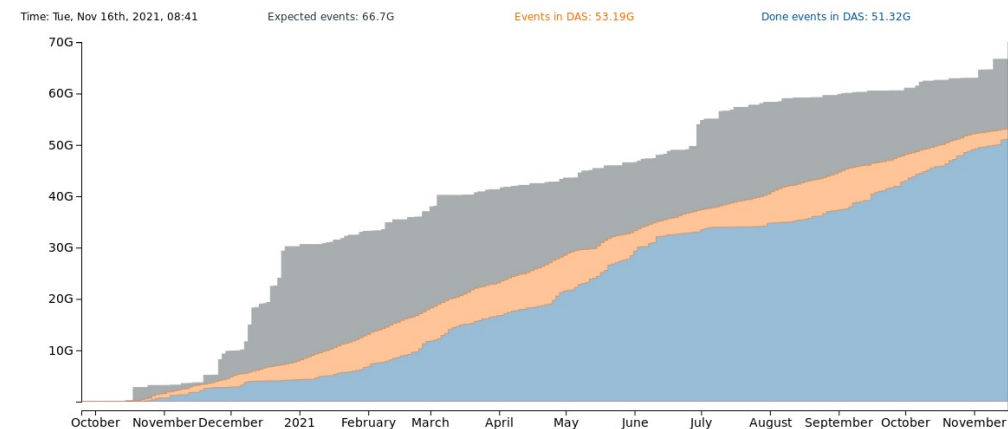
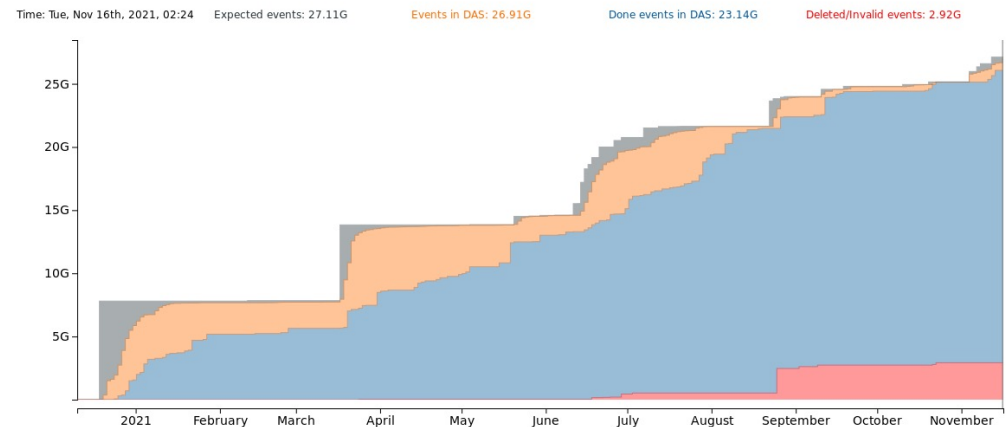
- best ever for CMS

CMS made 53 billion new events of full simulation MC

- with 14 billion events more to go

The B-parking data processing is in full production

- 12 billion events available, 8 billion processed



Phase II upgrades



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The ambitious CMS Phase II upgrade



CMS Experiment CERN
@CMSEXperiment

The CMS experiment continues to push technologies during its progression toward HL-LHC.



The installation of the Gas Electron Multiplier GE2/1 demonstrator chamber has been successfully completed!



Learn more here: 📌

cms.cern/news/demonstra...

@CmsMuon

#CERN #CMSexperiment

4:00 pm · 12 Nov 2021 · Twitter Media Studio

6 Retweets 2 Quote Tweets 30 Likes



Tweet your reply

Reply



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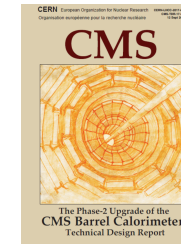
The ambitious CMS Phase II upgrade



L1-Trigger HLT/DAQ

<https://cds.cern.ch/record/2714892>
<https://cds.cern.ch/record/2759072>

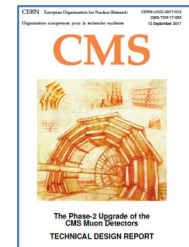
- Tracks in L1-Trigger at 40 MHz
- PFlow selection 750 kHz L1 output
- HLT output 7.5 kHz
- 40 MHz data scouting



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

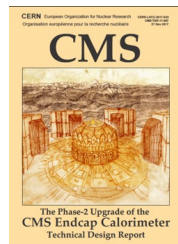
<https://cds.cern.ch/record/2283189>

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \approx 3$

Beam Radiation Instr. and Luminosity

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

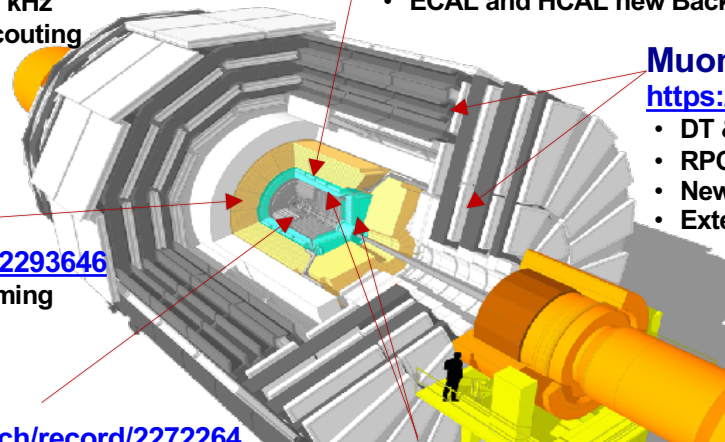
- Bunch-by-bunch luminosity measurement: 1% offline, 2% online



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>

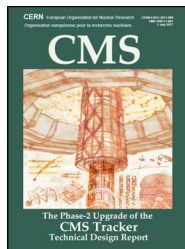
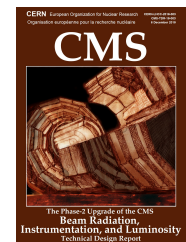
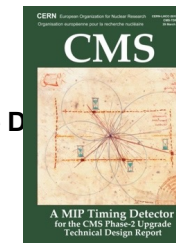
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \approx 3.8$

MIP Timing Detector

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

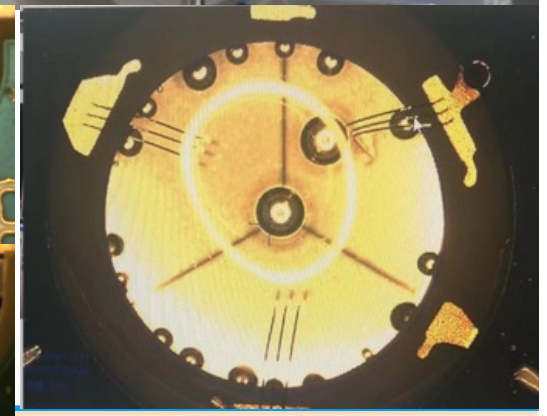
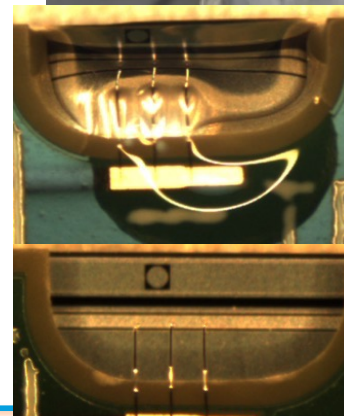
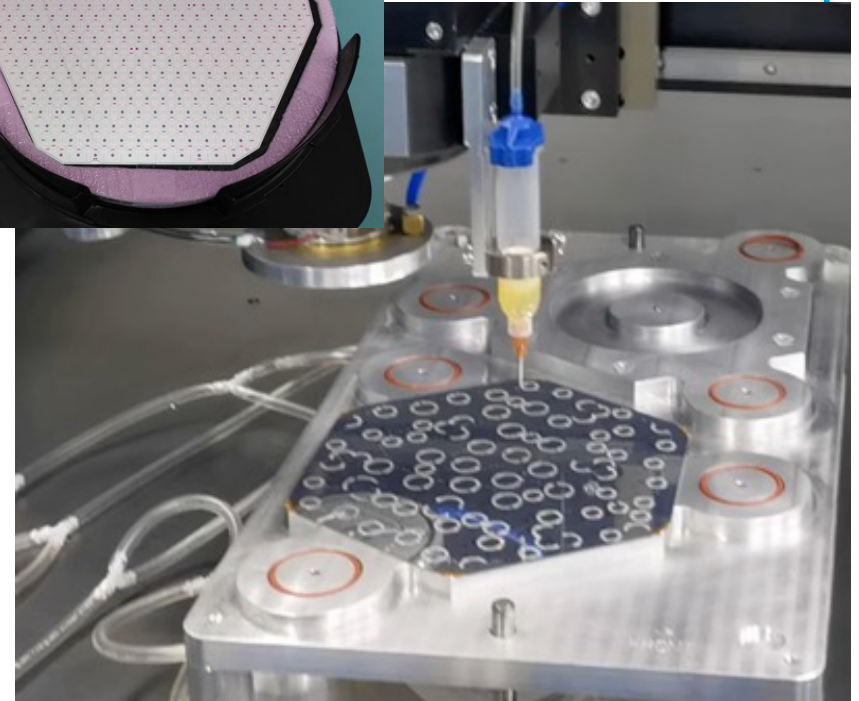
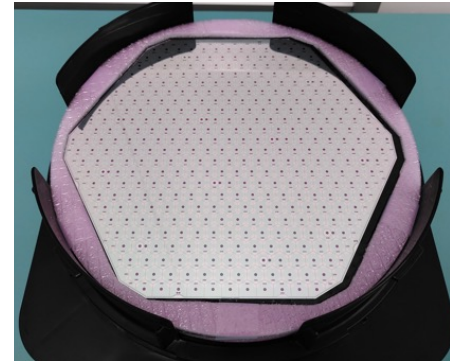
Precision timing with:

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

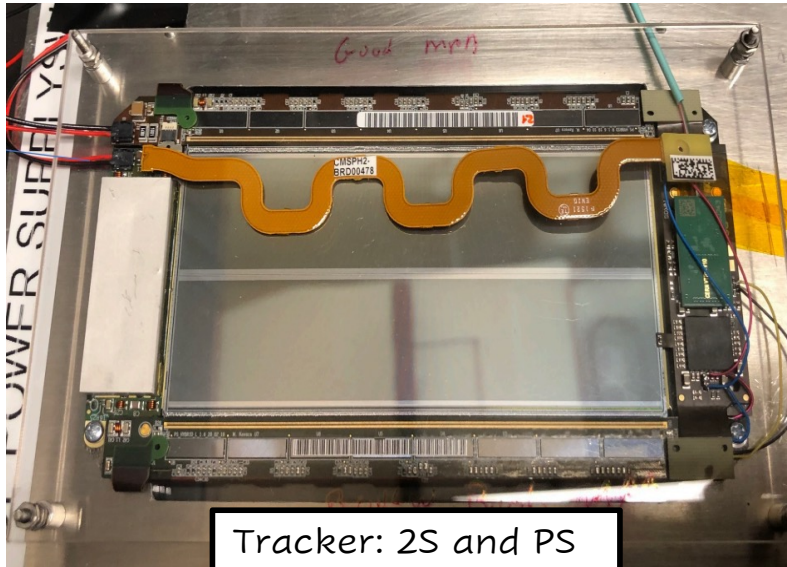


High-Granularity Calorimeter

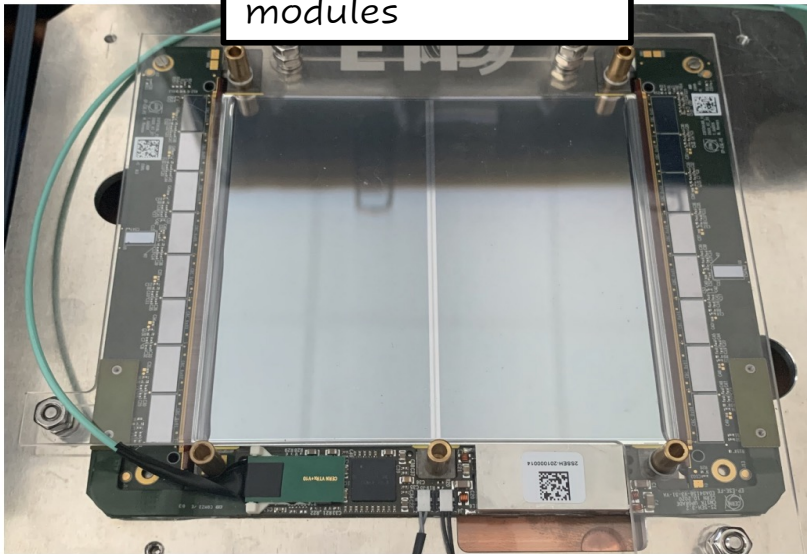
- Prototype silicon sensor testing concluded.
 - Next version(v2) sensors received and under test.
 - Full size sensors order is imminent.
- Read-out chip prototypes in various states of readiness
- Beam-tests with silicon modules completed
- SiPM-on-Tile part:
 - SiPM market survey closed
 - Automated tile wrapping and tile-module assembly equipment operational



Tracker



Tracker: 2S and PS modules



Inner Tracker:

- Wafers received, first chip mounted in October is operational, testing ongoing
- Good progress with mechanical and electronics system

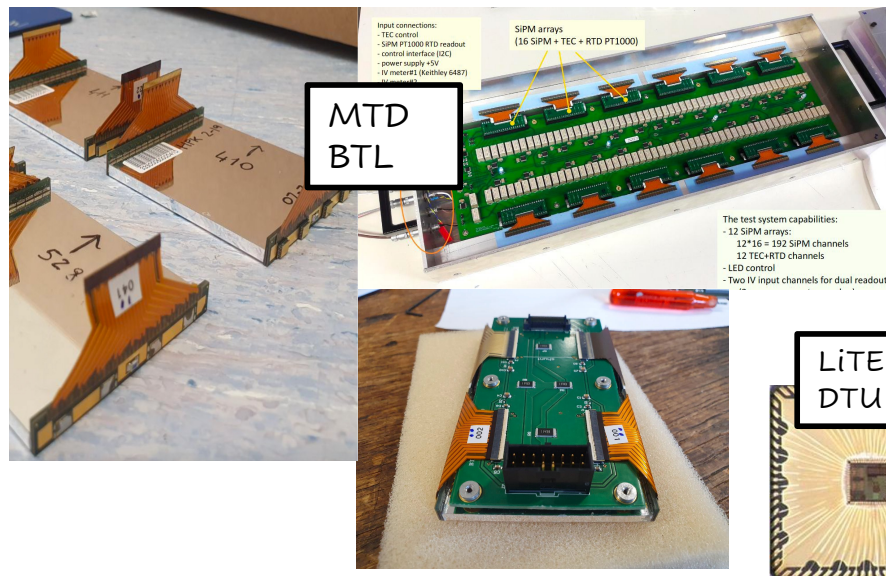
Outer Tracker:

- Steady sensor production ongoing (>20% done)
- Final ASICs being validated and qualified
- Final hybrid design being completed
- Engineering Design Review (STEP-3) held October

MIP Timing Detector, Muons, BCAL

Timing detector:

- Barrel thermoelectric coolers integrated in the design
- Barrel clock distribution and performance validated in test beams
- Endcap timing detector design nearing completion, first full tests of prototype readout in progress



Muons:

- GE2/1 on track to be installed YETS 23/24
- Muons electronics (DT, CSC, RPC) projects on track

BCAL:

- On track for preproduction versions in 2022
- Successful test beam validation last July

Physics Results and publications



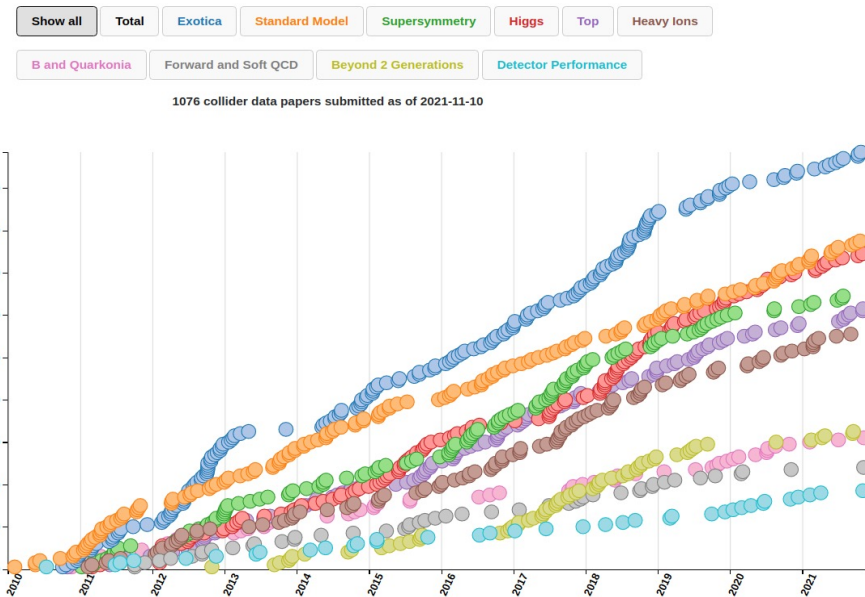
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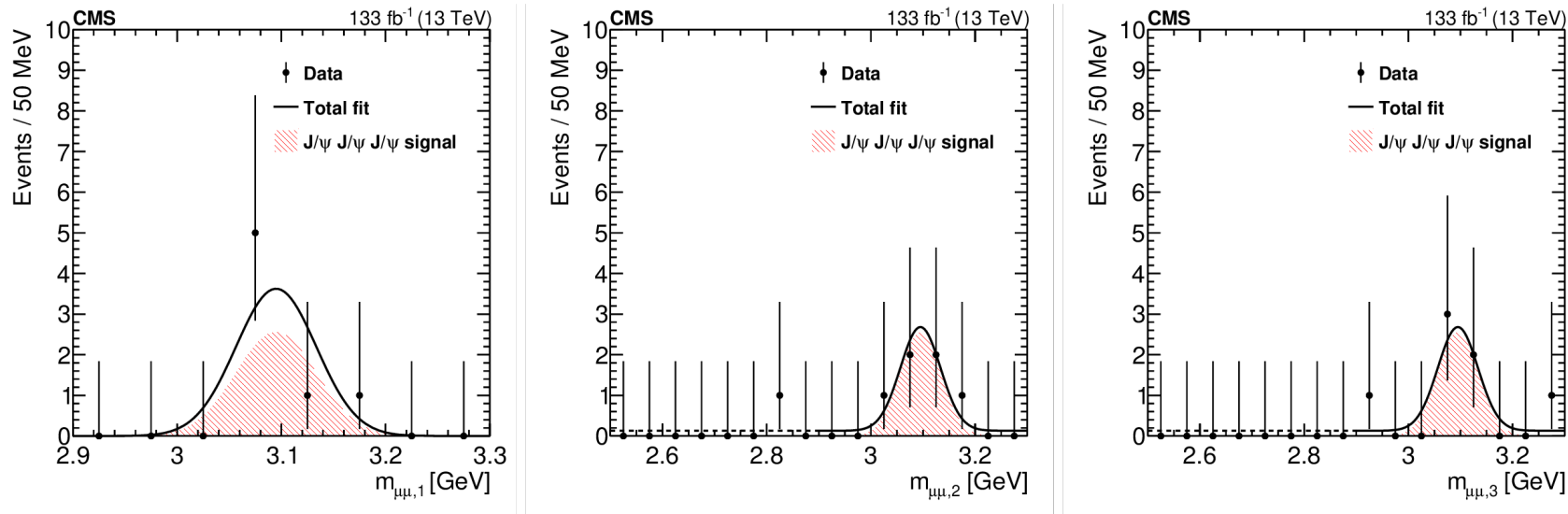
Analysis progress

- 17 new CMS papers since last LHCC
 - Steady rate of submissions, 1076 papers on collision data
- Run-2 exploitation far from being finished
 - Many measurements and searches still ongoing
 - Combinations and global interpretations of the analyses performed so far ongoing (e.g. Higgs combination, EFT interpretations)



- A large fraction of the ongoing analyses is now using CMS Run2 Legacy reconstruction and calibration (slide 15)

Observation of three simultaneous J/ψ



- Observation above 5 standard deviations
- (With assumption of factorisation of multiple hard scattering probabilities), Observed signal should be dominated by double- and triple-parton scattering
- Novel approach offering first look at the simultaneous production of three heavy particles
- [CERN news article](#) top visited CERN web page two weeks ago

[arXiv:2111.05370](#)



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LHCC - CMS Collaboration

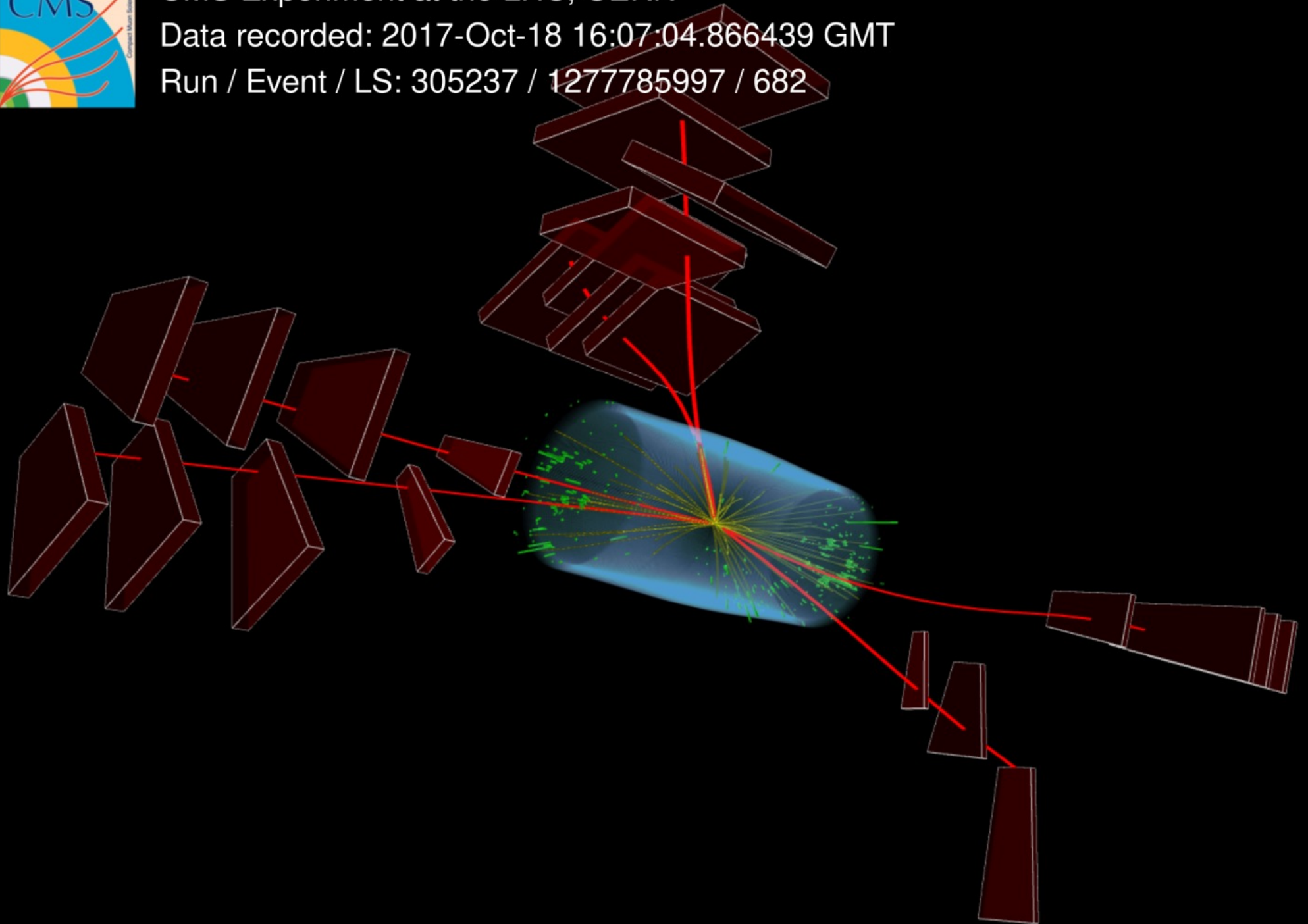
25



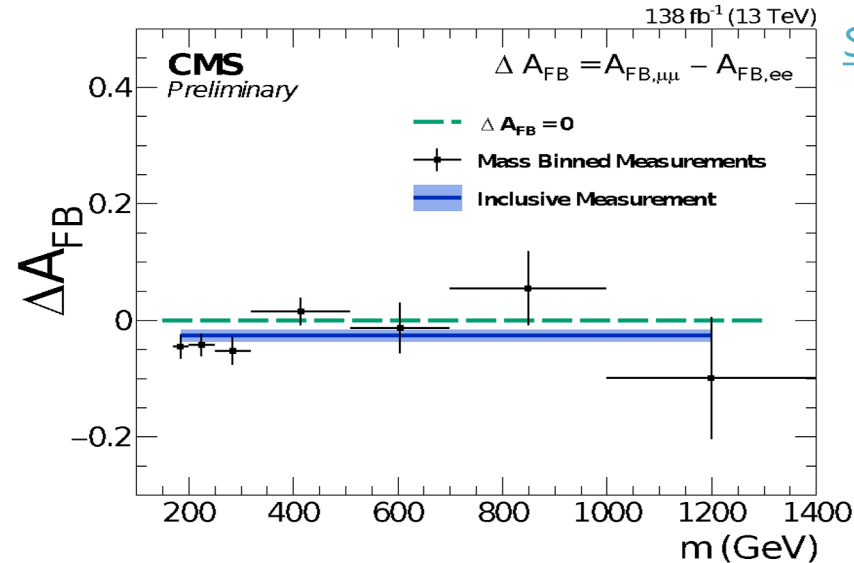
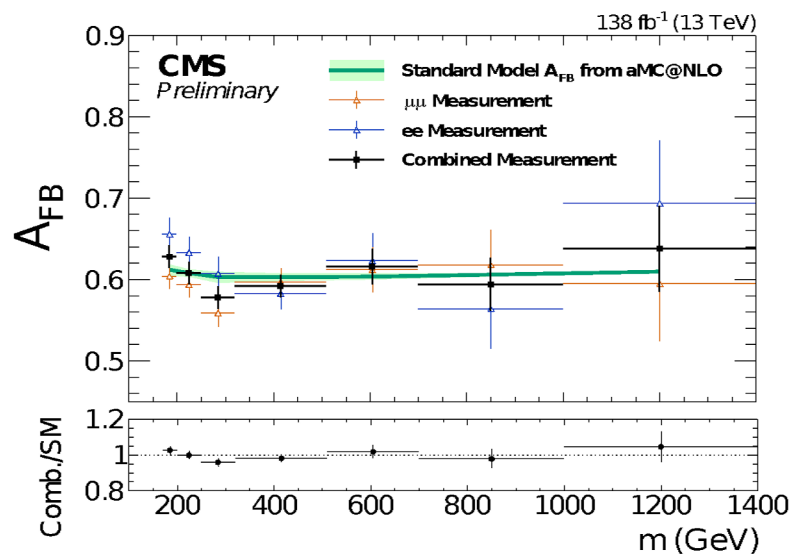
CMS Experiment at the LHC, CERN

Data recorded: 2017-Oct-18 16:07:04.866439 GMT

Run / Event / LS: 305237 / 1277785997 / 682



Drell-Yan forward-backward asymmetry (A_{FB})



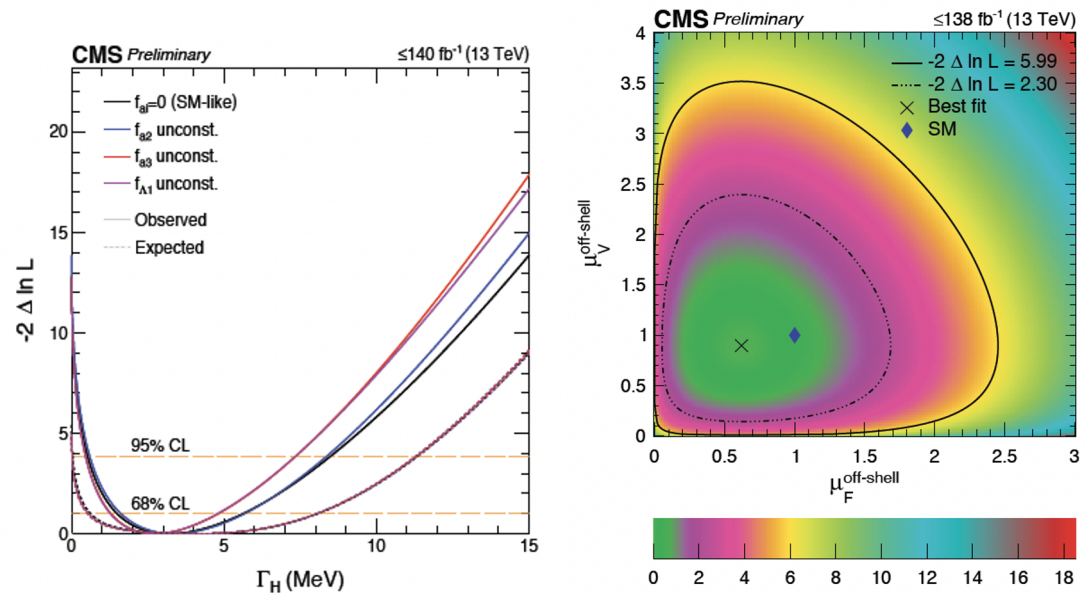
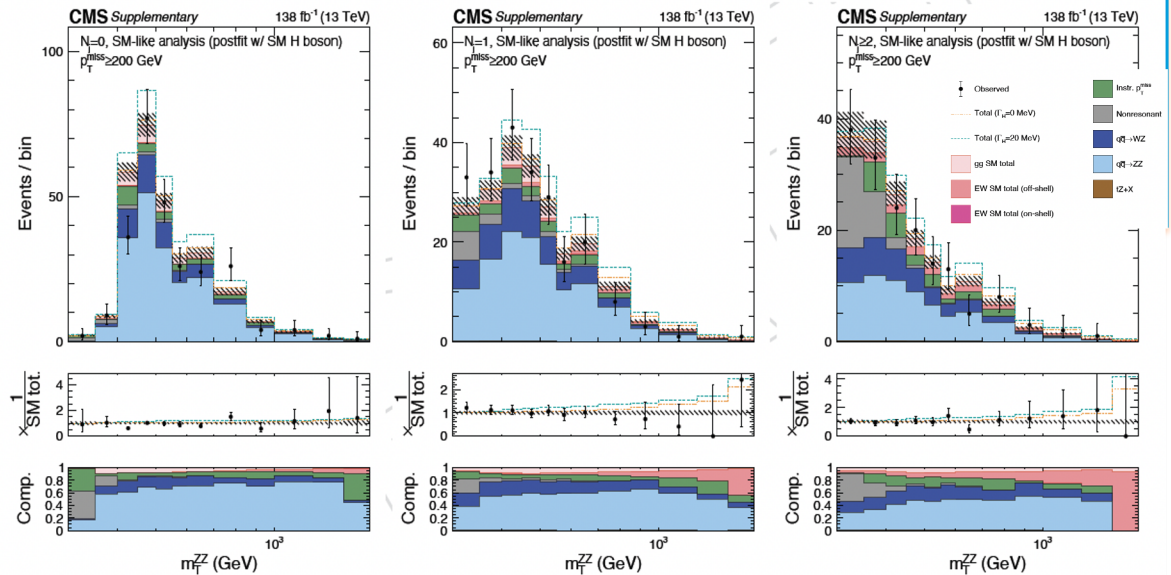
SMP-21-002

- A_{FB} asymmetry measured for electron and muon pairs with masses above 170 GeV
- Well-understood uncertainties from PDFs, lepton identification, and MC and background estimation statistical uncertainties
- Inclusive A_{FB} sees no deviations
- Comparison between leptons $\Delta A_{FB}(\mu\mu-ee)$ deviates from SM expectation (of 0) at 2.4 standard deviations
- Also: upper limits on additional bosons: Z' mass > 4.4 TeV

Off-shell Higgs with ZZ in 2l2ν and in 4l

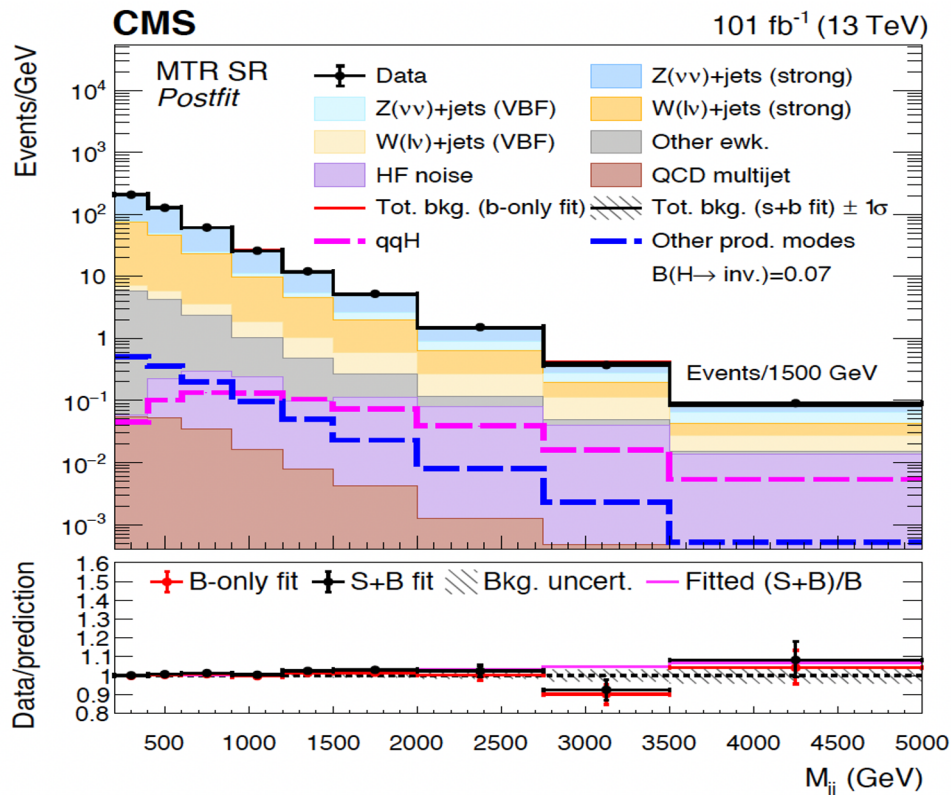
HIG-21-013

- Study Higgs production in ZZ channel
- Evidence for off-shell Higgs boson (3.6 standard deviations)
- Higgs total width: $\Gamma_H = 3.2^{+2.4}_{-1.7}$ MeV
- Also provides measurements of μ in off-shell scenarios and tests effect of anomalous couplings on Γ_H



Higgs decaying to invisible particles

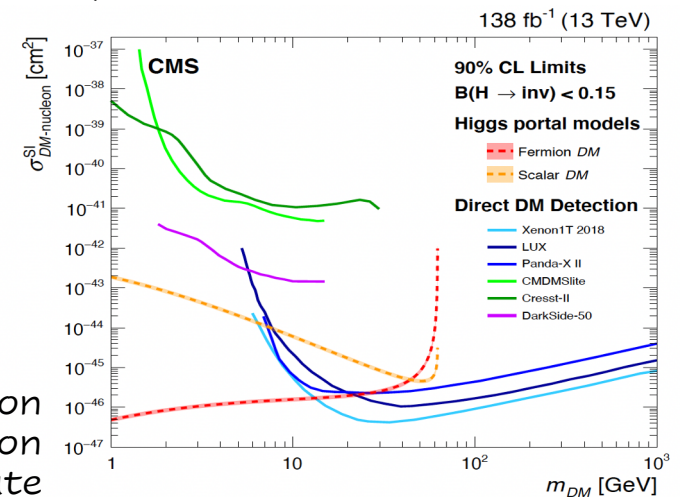
HIG-20-003



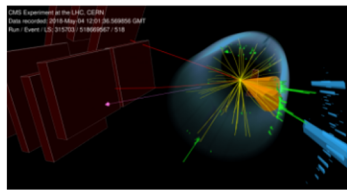
- Search in the VBF Higgs production mode
- Also targets events at lower Higgs boson transverse momentum
- New methods to constrain dominant Z+jets background improve results vs 2016 analysis more than statistics alone
- M_{jj} of jet pair produced by VBFH used as a discriminating variable to separate the signal and V+jets backgrounds

Observed(expected) upper limit of 0.17 (0.11)
Stringent limit on $B(H \text{ inv})$ in VBF

Complementary to Direct Dark Matter detection experiments in $m_{DM} < 12$ (6) GeV, assuming a fermion (scalar) dark matter candidate



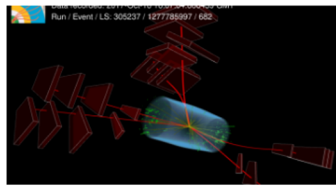
Physics Briefings



TWICE THE HIGGS, TWICE THE FUN!
01 NOV 2021

The Higgs boson, once the sought-after holy grail of particle physics, has now been with us for almost a decade. By now physicists are able to use the Higgs boson itself as a tool for the next discovery beyond the standard model. Interestingly...

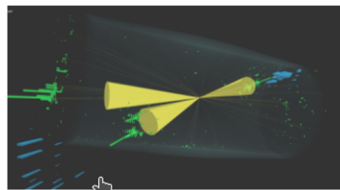
[READ MORE](#)



TRIO OF J/ψ PARTICLES IN ONE GO
29 OCT 2021

High-energy particle accelerators are unique tools to study the structure of matter at the shortest distances. The most powerful accelerator today is the CERN Large Hadron Collider (LHC) that has so far collided beams of protons up to center-of-mass...

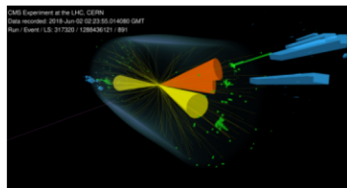
[READ MORE](#)



WWW.TRIBOSON.CMS 25 OCT 2021

Apart from the "World Wide Web," three Ws may also have a different interpretation in the LHC era. The standard model of particle physics is a mathematical construct that connects three of the four fundamental forces of nature and classifies all...

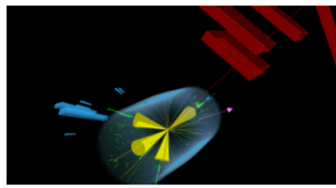
[READ MORE](#)



DOES THE BEHAVIOUR OF THE HIGGS BOSON MATCH THE EXPECTATIONS?
13 OCT 2021

The standard model of particle physics is our current best theory to describe the most basic building blocks of the universe, the elementary particles, and the interactions among them. At the heart of the standard model is a hypothesis describing...

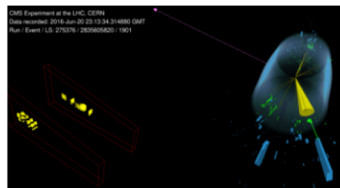
[READ MORE](#)



LHC AS THE VECTOR BOSON COLLIDER
13 SEP 2021

After the Higgs boson discovery in the year 2012, the standard model of particle physics offers a complete and consistent description of elementary particle interactions that, despite the many attempts, has not been falsified by experimental...

[READ MORE](#)



A NEW WINDOW INTO THE SHADOW WORLD: EXOTIC PARTICLE DECAYS IN THE MUON DETECTORS
27 AUG 2021

As physicists seek the elusive particles that may reveal a new understanding of the universe's inner workings, one intriguing possibility is the conceivable existence of new particles that live in a shadow universe, called the "dark sector." The...

[READ MORE](#)

CERN COURIER

DETECTORS | FEATURE

Counting collisions precisely at CMS

3 November 2021

Beyond the setting of new records, precise knowledge of the luminosity at particle colliders is vital for future physics analyses, explains Georgios K Krintiras.



Intense The start of Run-2 physics in the CMS control room. Credit: CERN-PHOTO-201506-130-18

Briefings and their accompanying social media reach hundreds of thousands of interested members general public per month



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Towards Run 3 physics

- Exploitation of the early Run3 data creates excellent physics opportunities
 - New SM process measurements at 13.6 TeV (often few 1/fb are sufficient)
 - Searches finishing Run2 with some ~ 3 sigma local excess use data top-up
- Opportunity for innovation as well
 - Well set to try creative new ideas on triggers, parking, scouting



Outlook & Conclusion

- Complete CMS detector taking data in global runs
 - And learning from that data!
- Run 3 preparation is on track
 - Adapting CMS schedule to LHC operations
- Several Phase II upgrade milestones reached, making progress everywhere
- As always, exciting new (physics) CMS results in past, present and future

backup

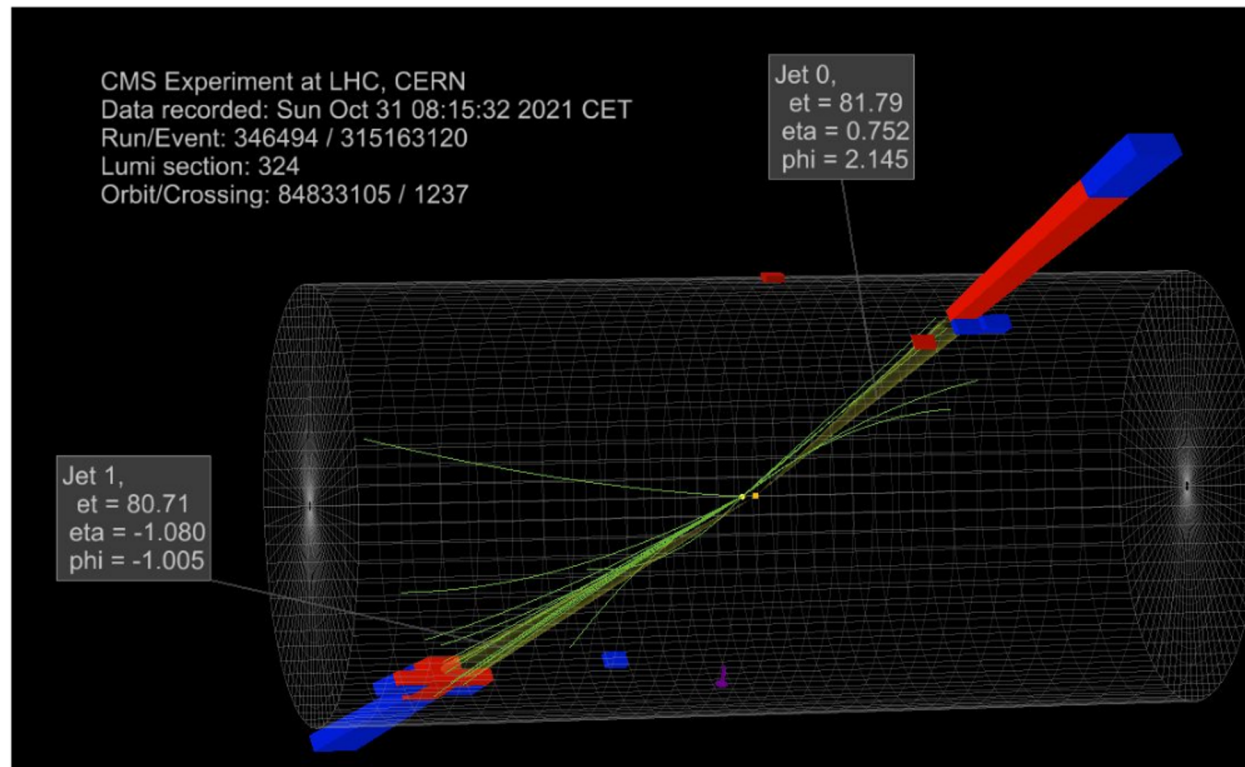


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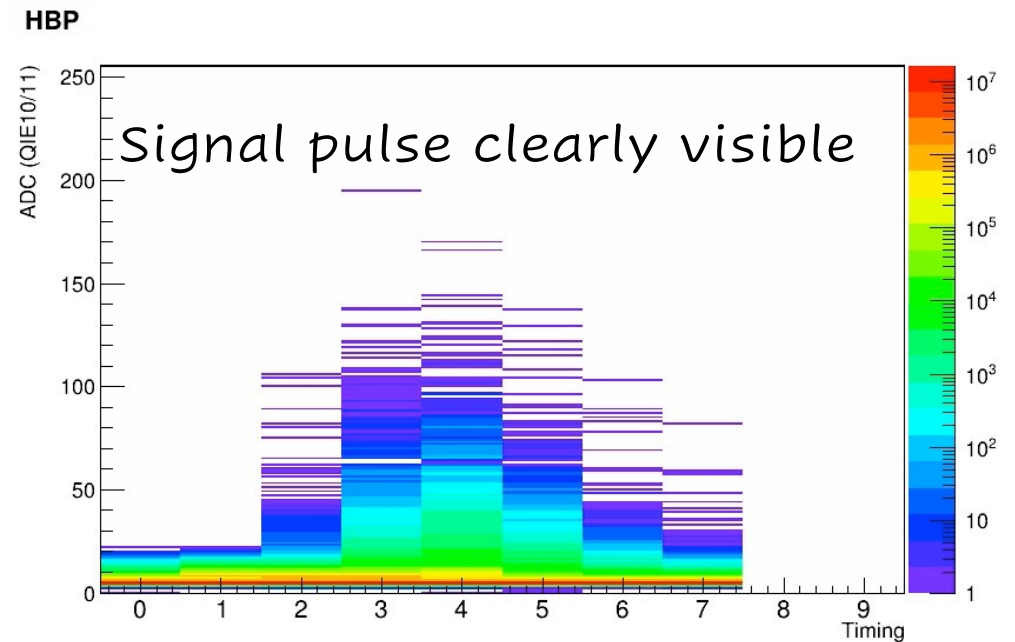
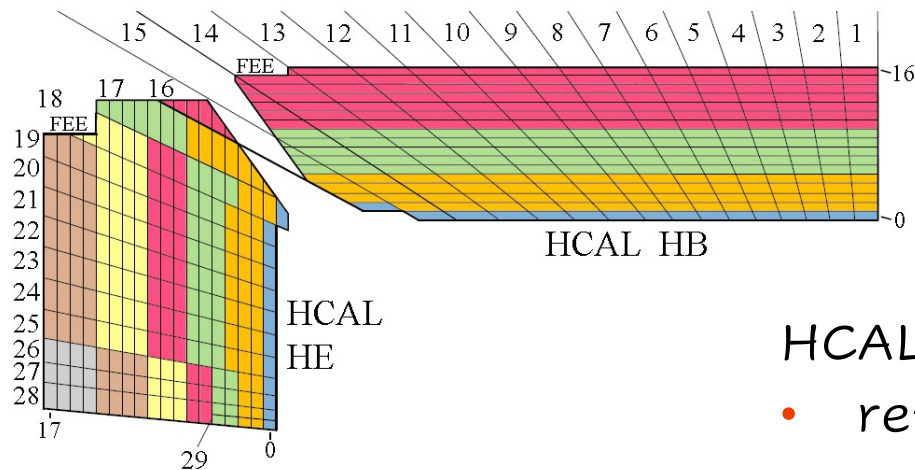
Pilot beam: physics as expected



This event contains 2 LI jets with E_T 91/83 GeV

HCAL during pilot beam test

ADC count in the upgraded HCAL barrel as a function of 25ns (clock) time slices during pilot beam test

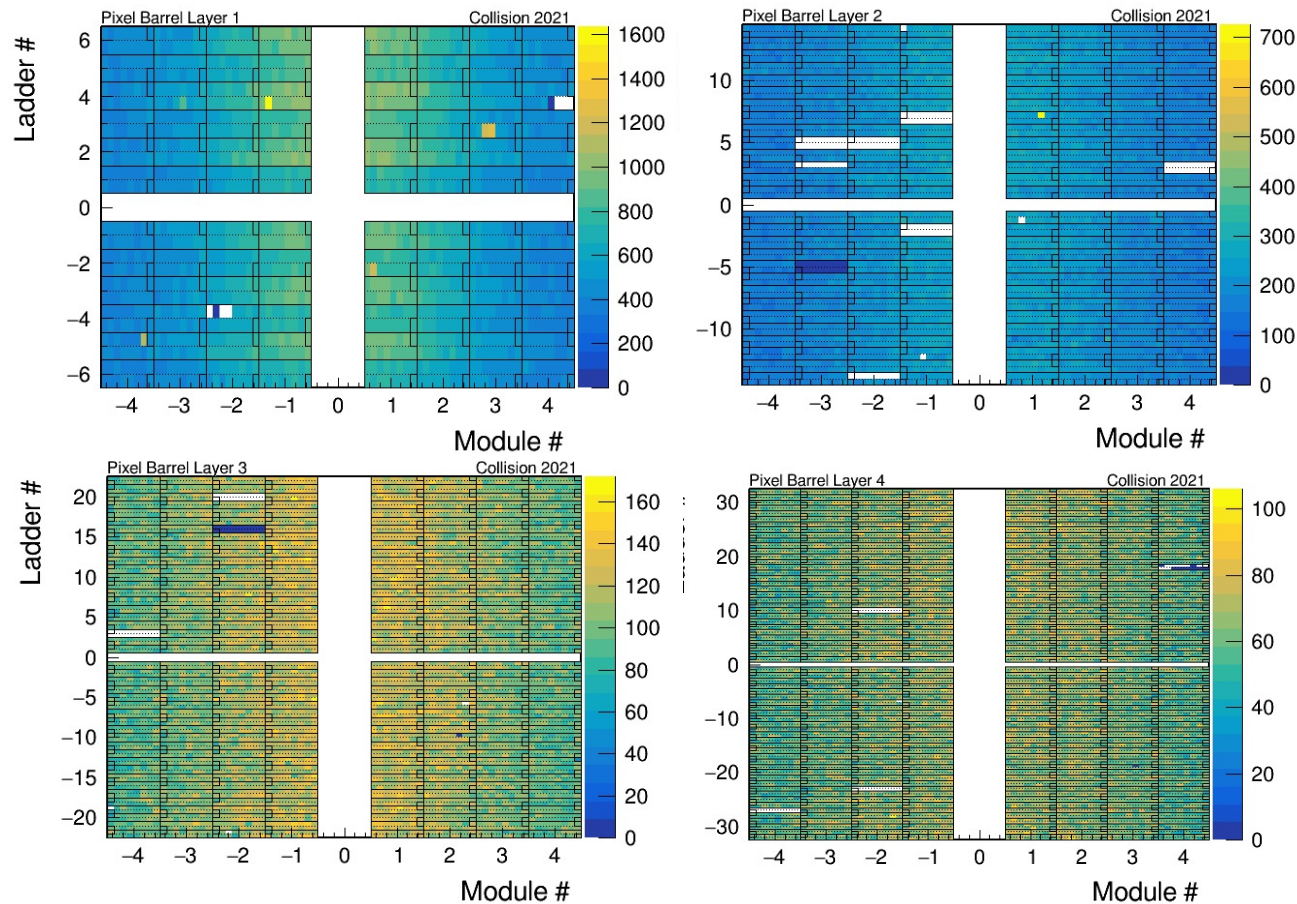


HCAL Phase I upgrade:

- replaces HPDs with SiPMs
- more longitudinal segments
- Increased electronics redundancy
- Increased readout data rates
- Addition of signal time measurement

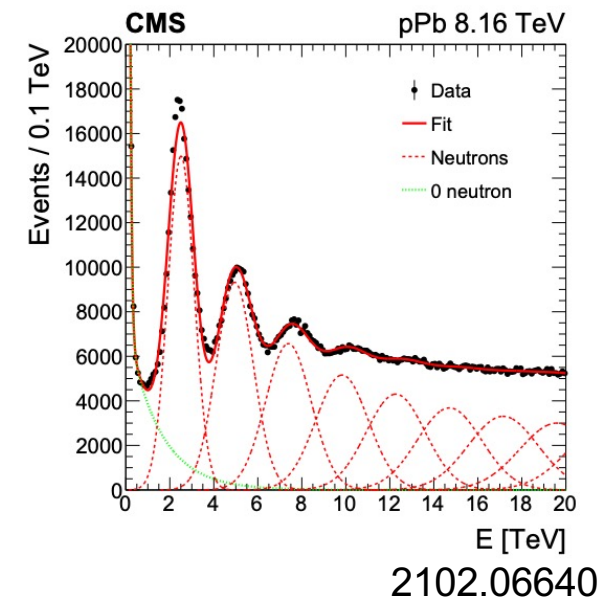
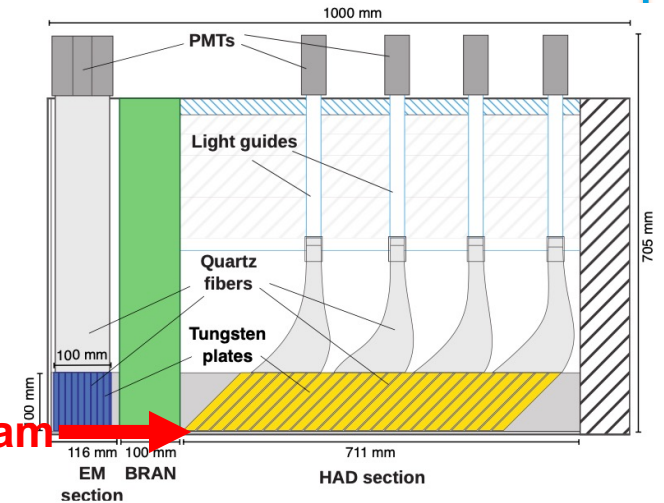
Pixel during first stable beam

- Active fraction of Layer 1 is 99.5%,
- BPix and FPix are around 99% and 98%



Zero Degree Calorimeter commisioning

- Very forward, 140 meter downstream from CMS ($|\eta| > 8$)
- forward information during HI collisions
 - Improved centrality
- Can separate individual forward neutrons, photons
- ZDC timed in with rest of CMS during recent pilot runs!



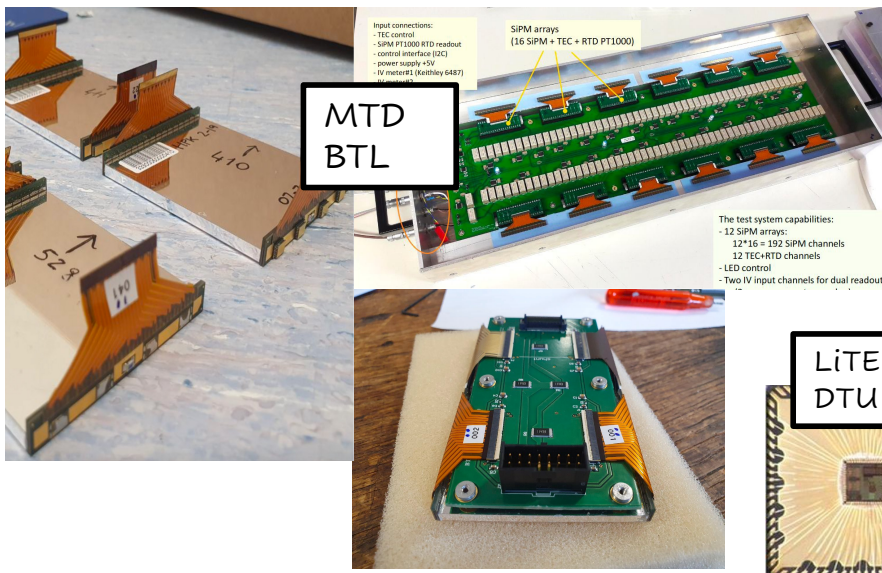
MTD, Muons, BCAL

MTD – Barrel:

- Thermoelectric coolers (TECs) integrated in the design
- Market Survey for LYSO and SiPMs arrays concluded
- Clock distribution exceeds expectation/specs
- Full-chain tests and test beam validated BTL performance
- Final ASIC (TOFHIR2B) prototype submitted

MTD - Endcap

- ETROC2 (full size and functionality chip) design nearing completion
- LGADs: Market Survey launched
- Progress in first full-chain tests of prototype readout boards



Muons:

- GE2-1 demonstrators installed; iRPCs to follow
- GE2/1 full detector on track to be installed YETS 23/24
- ME0 R&D progressing well
- Muons electronics projects:
 - DT: Phase2 Slice Test ready for Run3 data taking
 - CSC: ODMB7 preproduction board step successful
 - RPC: Link System preproduction boards ready

BCAL:

All components on track for preproduction versions in 2022
 Successful test beam validation last July
 Production ASICs (V2) expected later this year

L1 Trigger:

- progress in testing different FPGAs and optics