# CMS

# Status Report

*Sept. 1st, 2021 - 147th LHCC Meeting Open Session*

*Livia Soffi on behalf of CMS*

INFN ROMA
Istituto Nazionale di Fisica Nucleare
Sezione di Roma

# Outline

Long shutdown 2 activities aiming at Run 3

Computing operations and data processing

Physics analyses and publications

Phase 2 progress

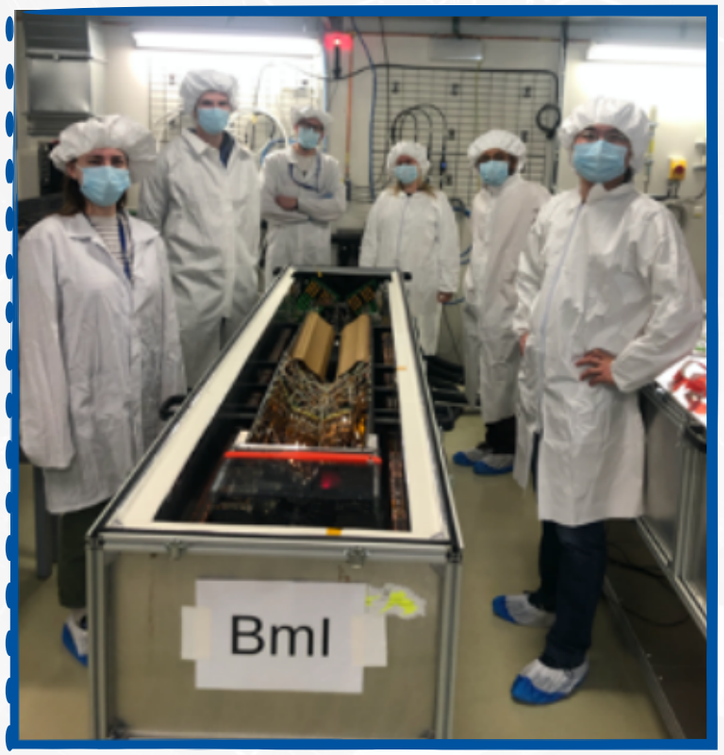
# *Long shutdown 2 progress towards Run 3*

# CMS operations during the pandemic

- **Shift Leader and Technical Shifter** in the control room fulfilling safety rules
- DAQ, Trigger, and DQM shifter operating remotely
- Subdetector experts in PT5 only if nedeed

- Waiting for second elevator replacement before restarting public **underground visits  on Oct 4 2021** at the earliest

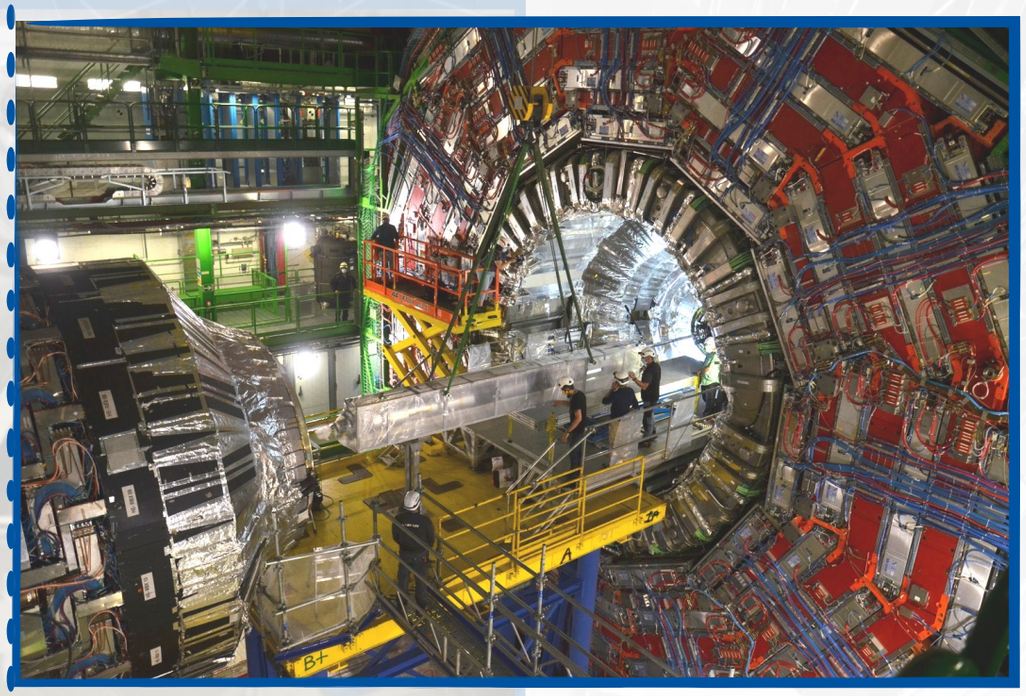
# Focus on Pixel installation




Pixel refurbishment completed: New Layer 1, DCDC converters, module exchange

6/2

# Focus on Pixel installation



Lowering BPix onto installation platform and insertion

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6/2

6/21

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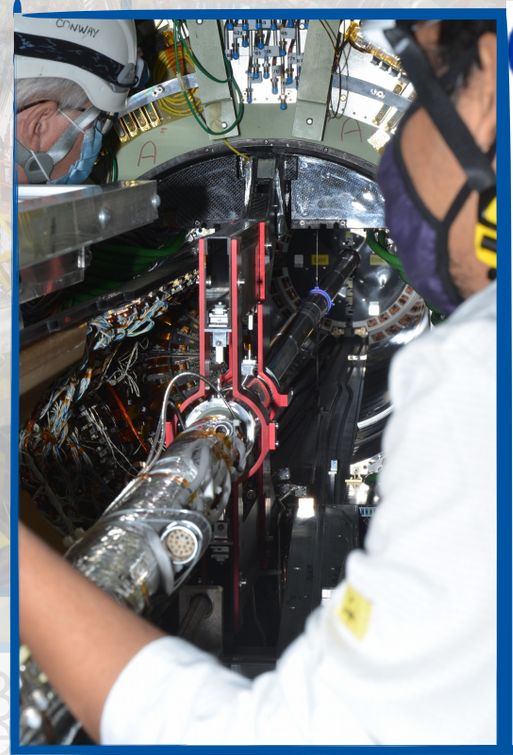



FPix installation and CERN Live Event

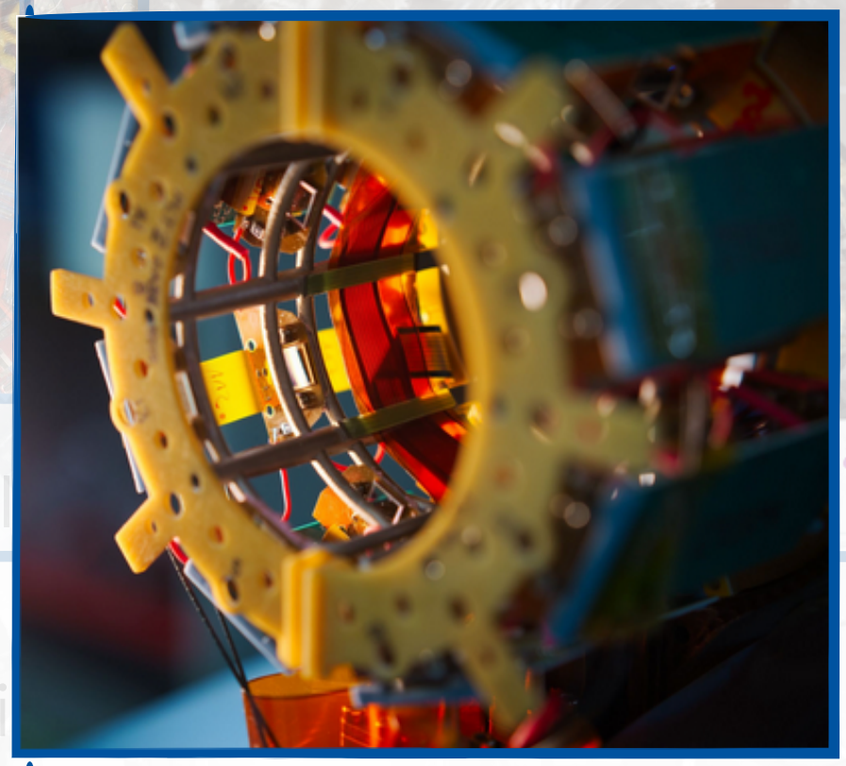
6/29

Lowering BPix platform and insertion completed: New Layer 1, DCDC converters module exchange

6/2 6/21

# Focus on Pixel installation





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6/2

Lowering BPix onto install platform and insertion

6/21

FPix installati

6/29

PLT/BCM installation

7/5

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Pixel refurbishment completed: New Layer 1, DCDC converters module exchange

6/2



6/21

Lowering BPix onto installation platform and insertion



6/29

FPix installation and CER


7/5

PLT/BCM in


Tracker bulkheads closed

7/10

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6/2



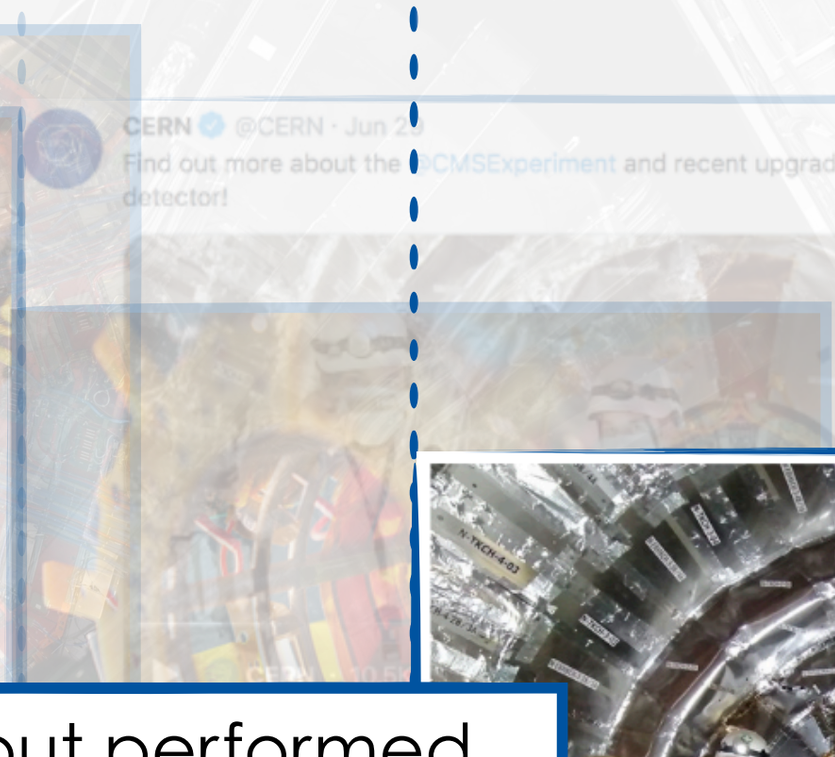
Lowering platform

6/21



FPix installation and CER

6/29




PLT/BCM in

7/5

Cold checkout performed successfully at -22C


Tracker bulkheads closed

7/10

# Beam Radiation Instrumentation & Luminosity (BRIL)

**Many Run 2 systems upgraded with new components**

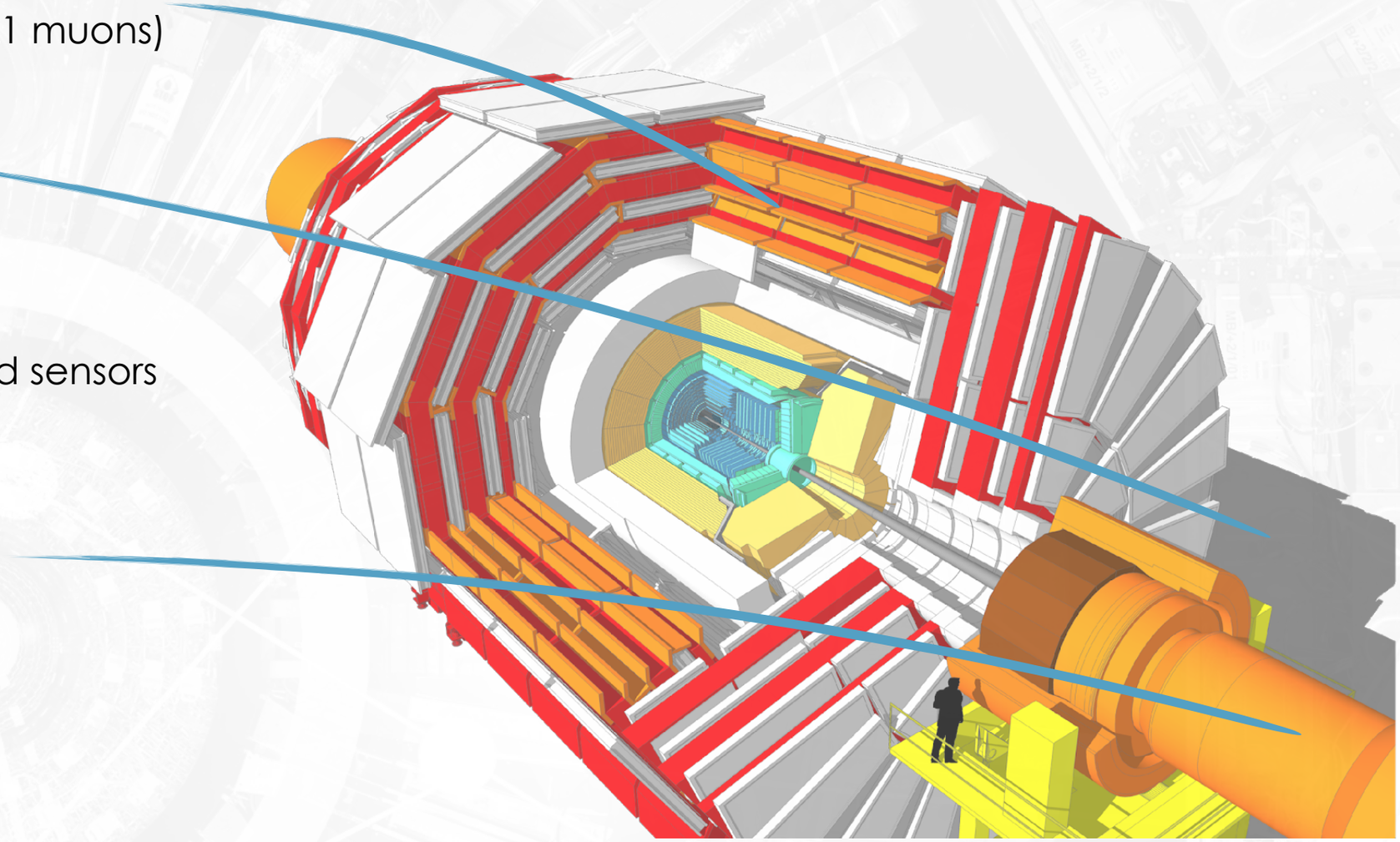
- **Trigger μ-scouting luminosity** (L1 muons)
New: Phase-2 BRIL firmware

- **REMUS, LHC RadMon**
New: more radiation monitors

- **BCML2** beam loss
New: sapphire & pCVD diamond sensors

- **Beam Halo Monitor**
New: XDAQ software

- **BPTX (~175 m) Timing/trigger**
New: oscilloscope upgrade



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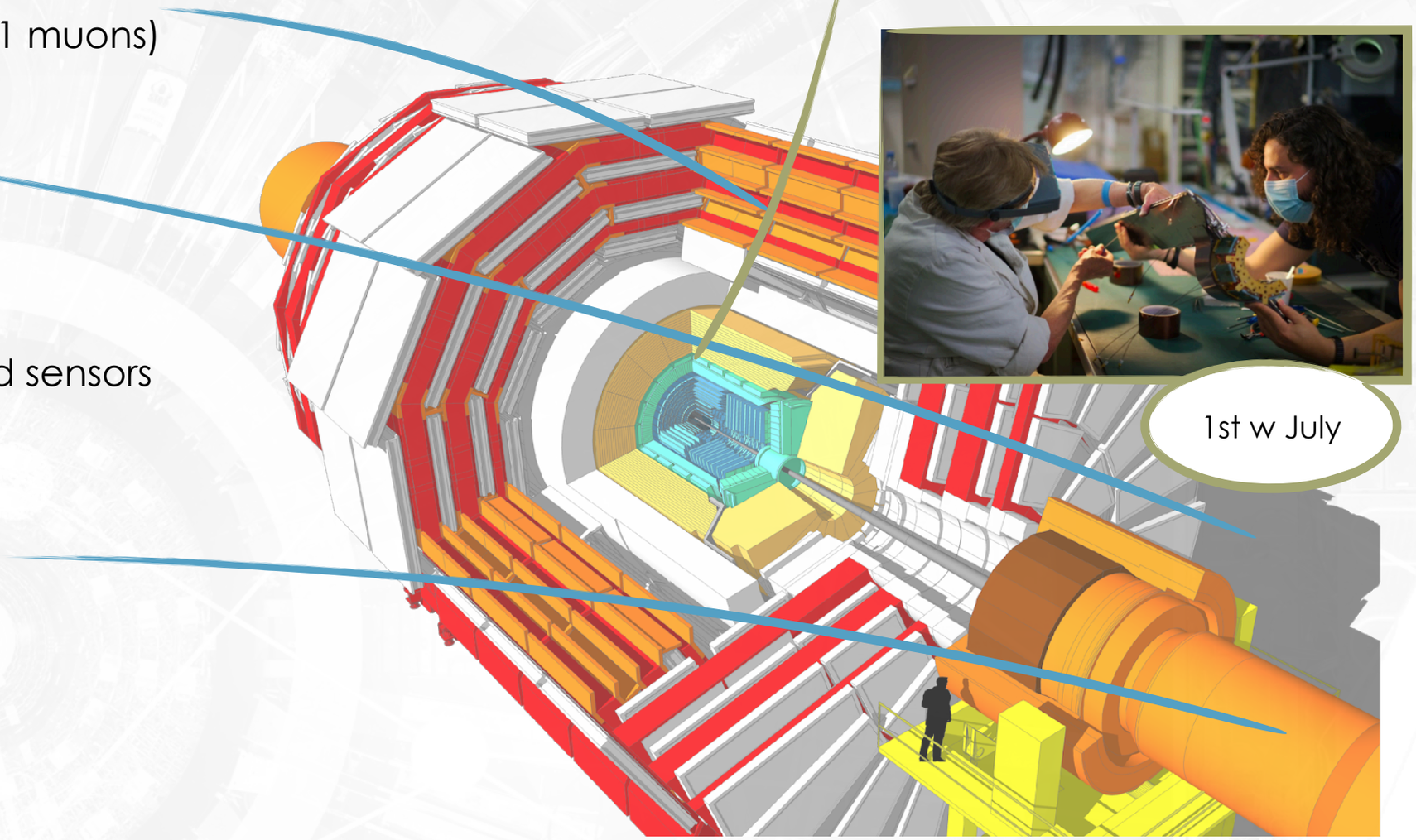
**Completely rebuilt and optimised for Run 3**

- **BCM1F** luminosity, beam-induced background
- **BCML1** beam loss
- **Pixel Luminosity Telescope** luminosity





1st w July

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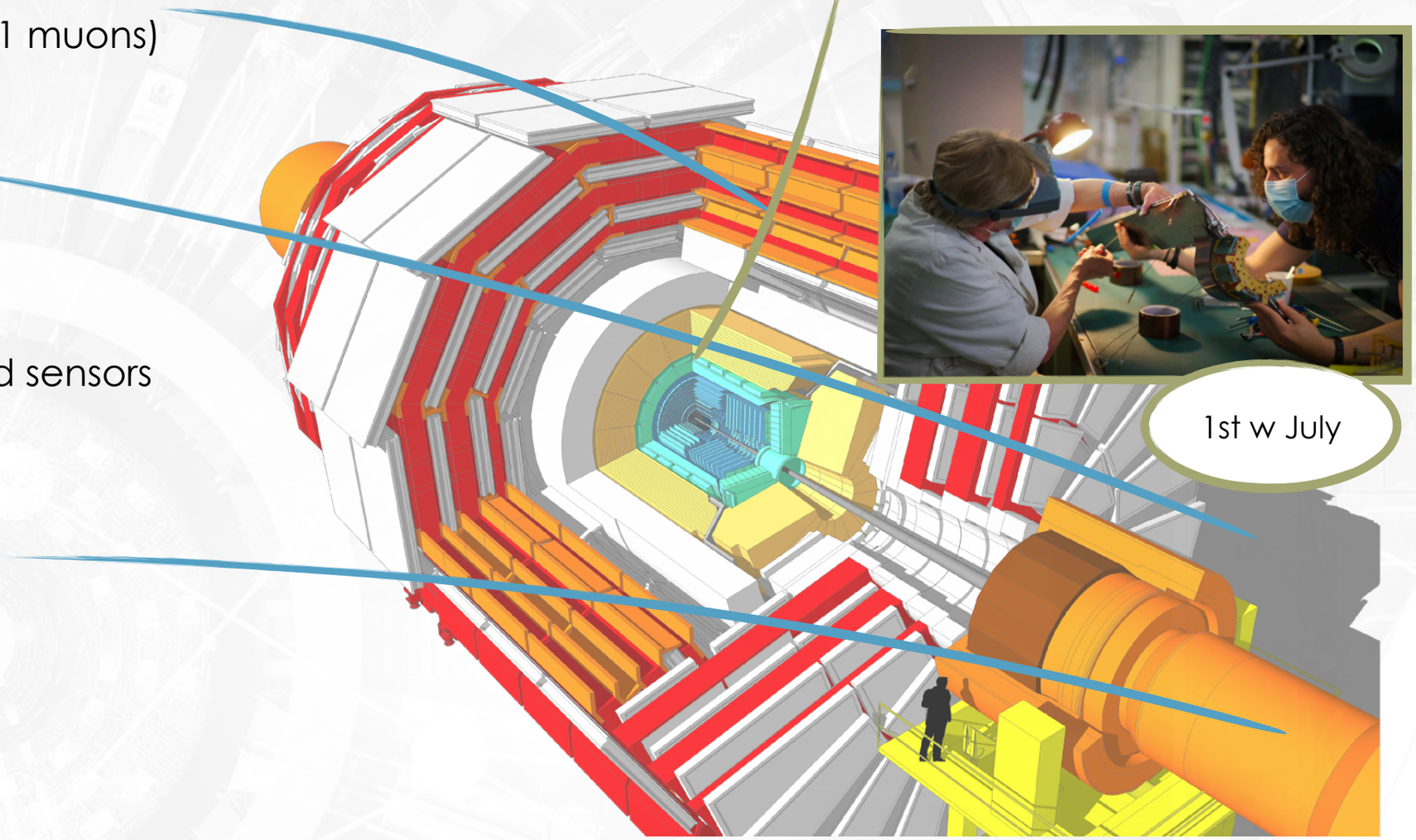
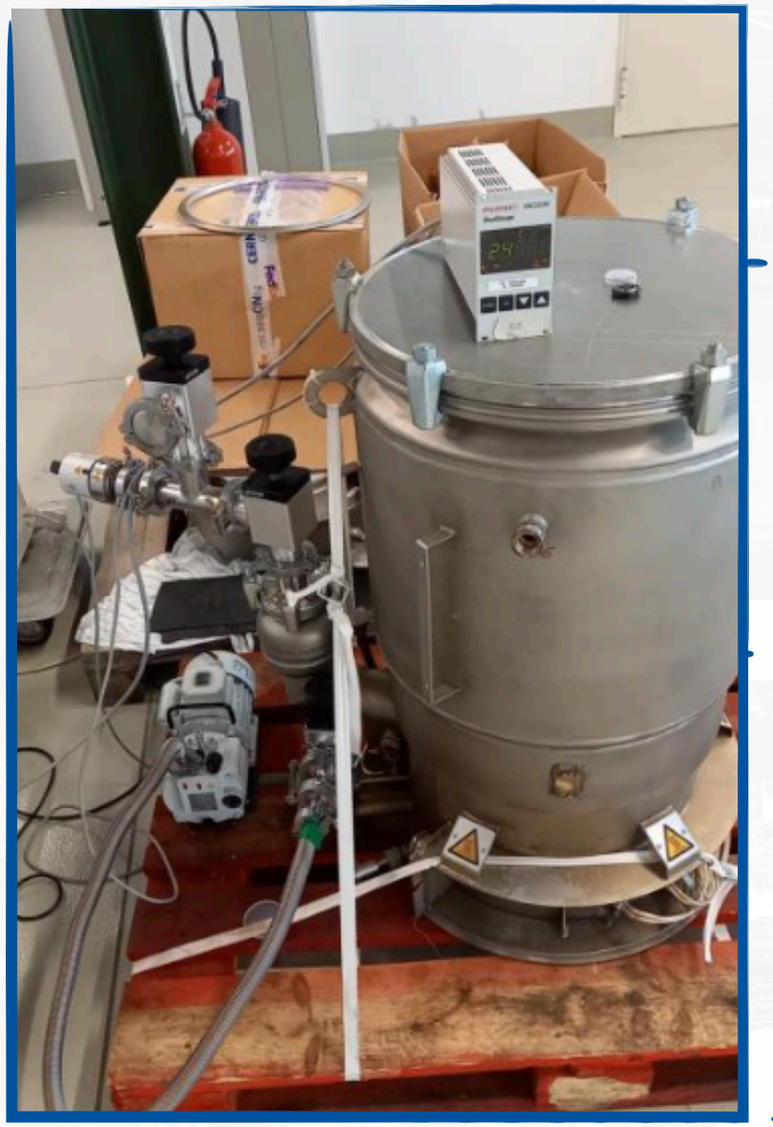



- **All BRIL systems installed**, being commissioned to be **ready** for the October LHC beam test!

# Latest from Point 5



Start CMS closing operations — 8/31

Magnet starts cooling down — 8/23

New magnet diffusion vacuum pumps commissioned — 8/17

- Ready for data taking by beginning of Oct.

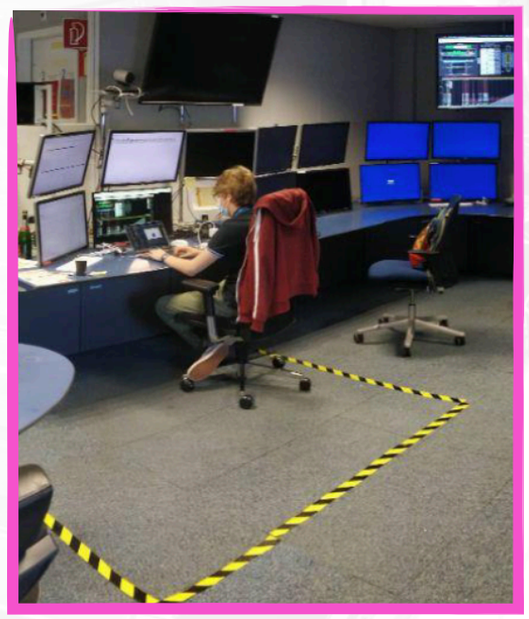
# Summer 2021 data taking

- Extensive **cosmic data taking** performed during summer:

**Cosmic Run at Zero Tesla (CRUZET) and Cosmic Ray data at Four Tesla (CRAFT)**
Crucial for CMS commissioning and used to **analyse, calibrate, and align detectors**

| Month | June | July | Aug | Sept -)ct | Oct | Nov | Dec | Jan | Fev | Apr |
|---|---|---|---|---|---|---|---|---|---|---|
| Activity | MWGR | CRUZET | CRUZET | CRAFT | Beam Test | MWGR | MWGR | CRAFT | CRAFT + First beams | **Ramp-up (coll.)** |
| When? | June 9-11 | Jul12... | ...Aug14 | Mid of Sept. to the Beam test . | Week 42-43 | Mid. of Nov | Mid. of Dec. | ~from mid of Jan to the first beams | From Feb21st | **Physics data** |
| Data taking | Yes (~3 days) | Yes (24/7) | Yes (24/7) | Yes (24/7) | Yes (during the BT) | Yes (~3 days) | Yes (~3 days) | Yes (24/7) | Yes (24/7) | **Yes (24/7)** |

- CRUZET started on **July 12th**: many centrally organized and local activities
- **CRAFT** to begin in early **October**, after magnet commissioning

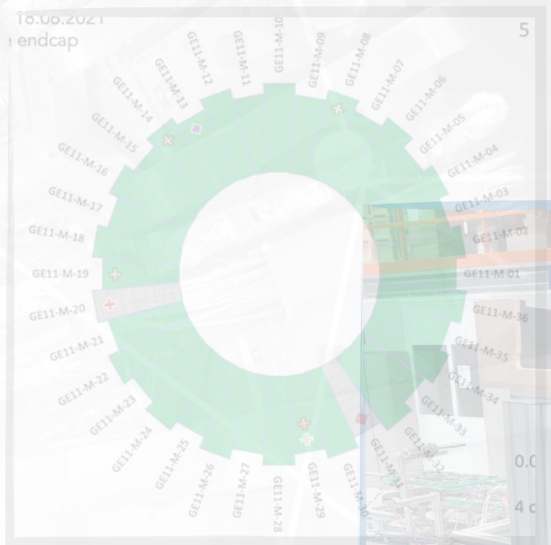


- **All subsystems running without major problems**. Several tests ongoing to improve stability of the system.

# CRUZET: Detector highlights

## Calorimeters

- **ECAL**: new features being tested extensively
  - Upgrade control and safety system
  - Improved algos for spikes rejections at L1
  - Corrosion issue found in preshower cooling system. Refurbishment campaign underway



## Muon Systems

- **GEM**: collect stats and commissioning
  - **Replacement of 2 GE chambers** in one endcap (VTRx baked **to monitor RSSI drifts)**
  - **Continuous monitoring** of chambers "not configuring" / "in error during run"
  - Good progress in the **GEM-Encap Muon Track Finder** L1 integration and commissioning

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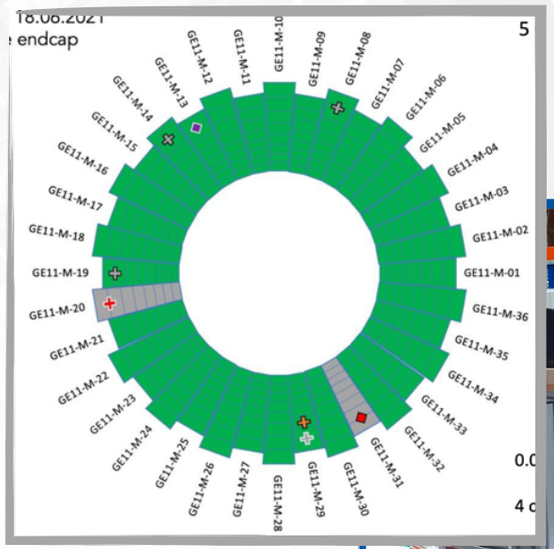


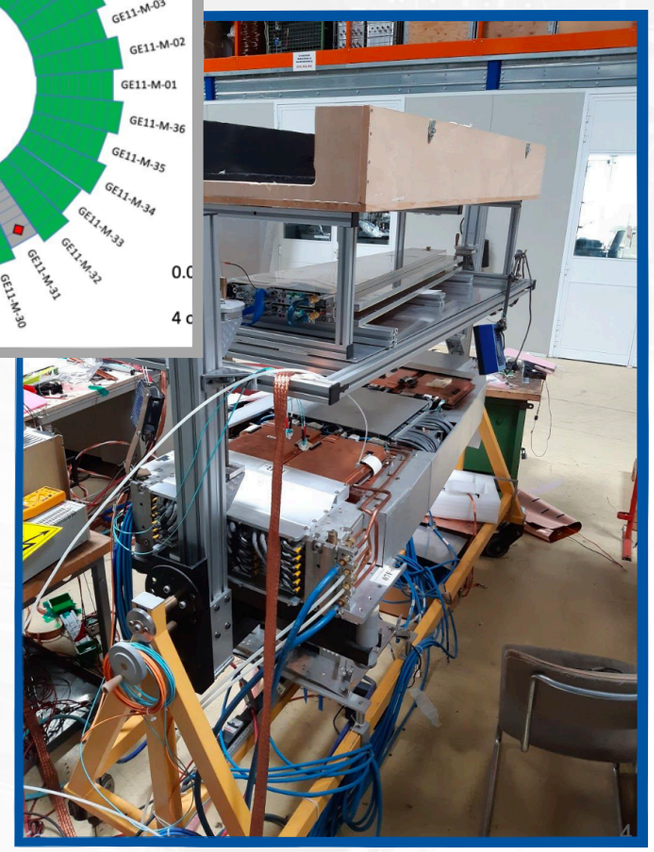

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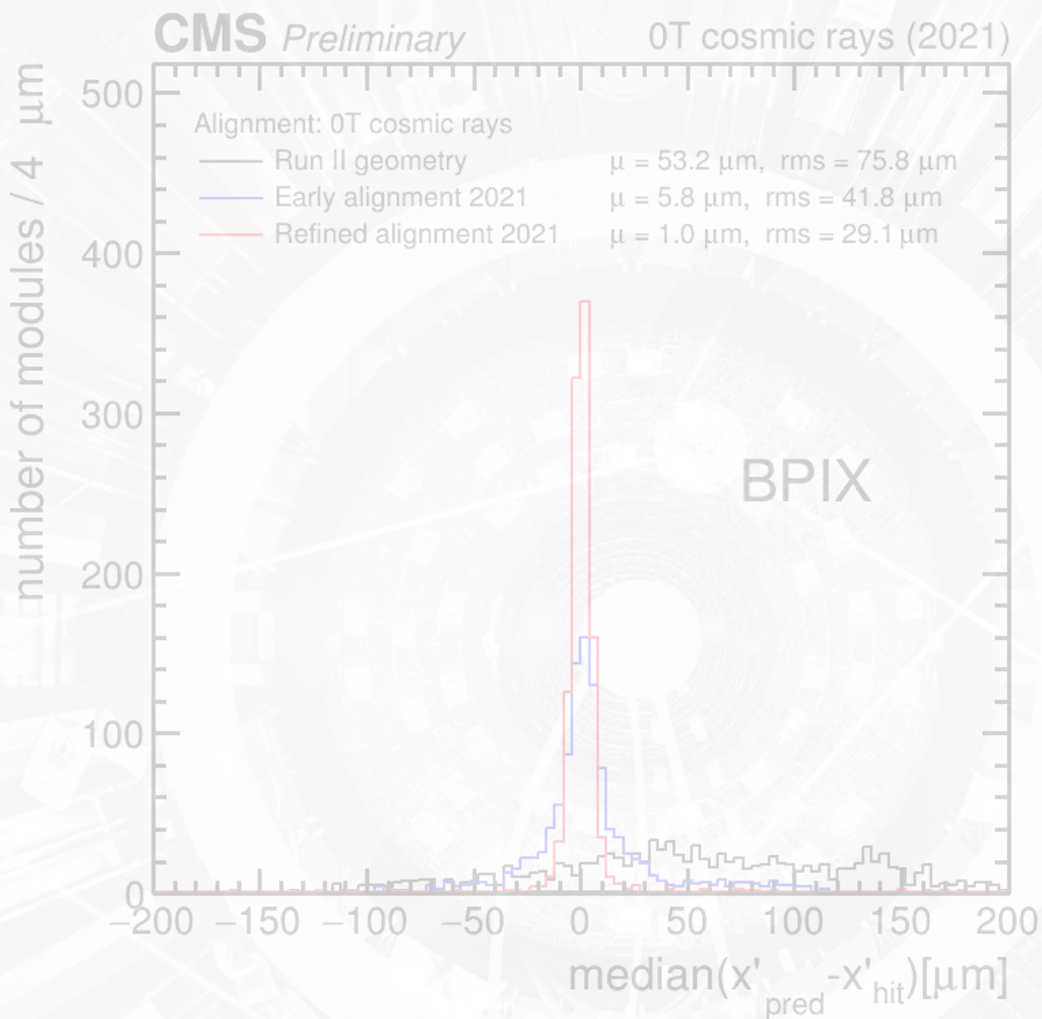
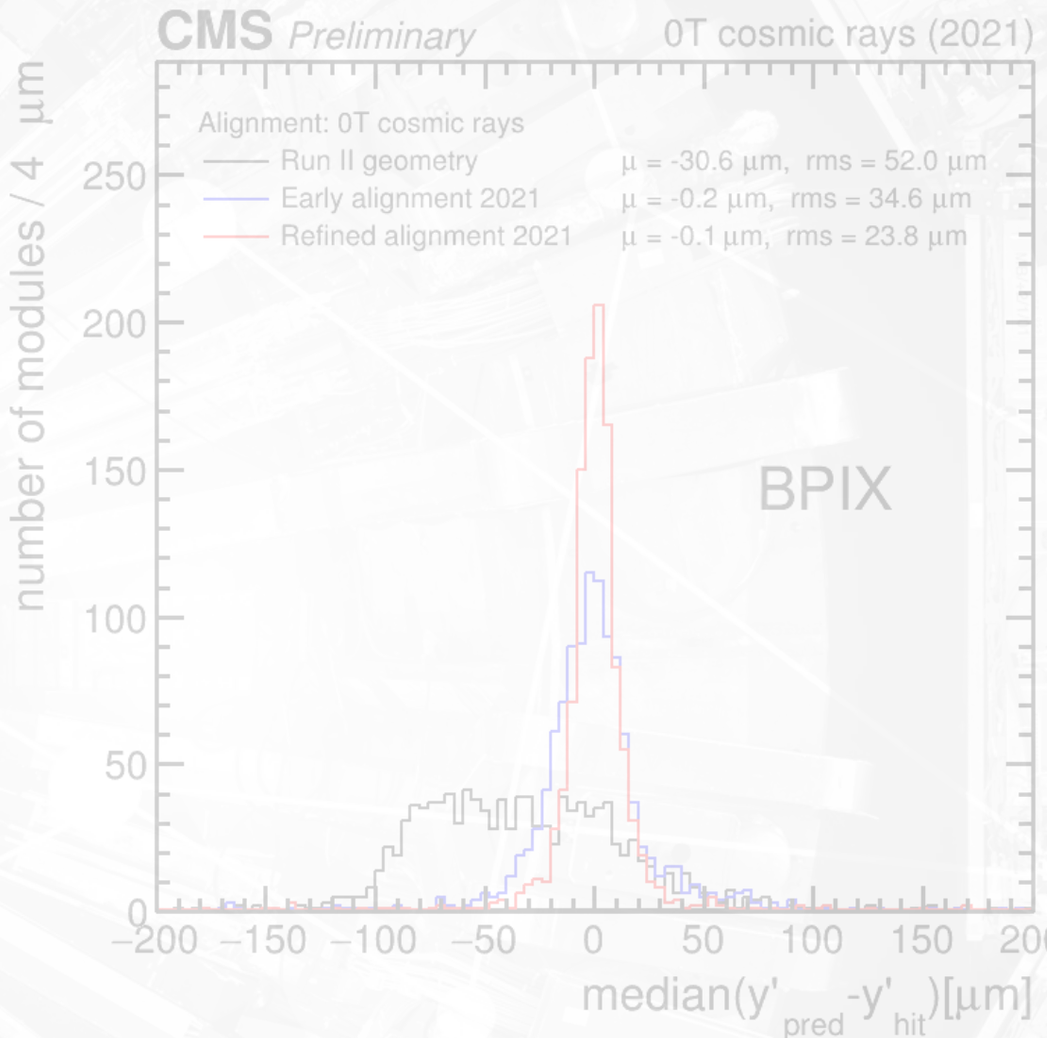
# CRUZET: Pixel alignment

- **Pixel working nicely after re-installation**
- BPix and FPix participated in global cosmic ray data-taking, **collecting 3.5 M events**
- Performed **initial track-based alignment**



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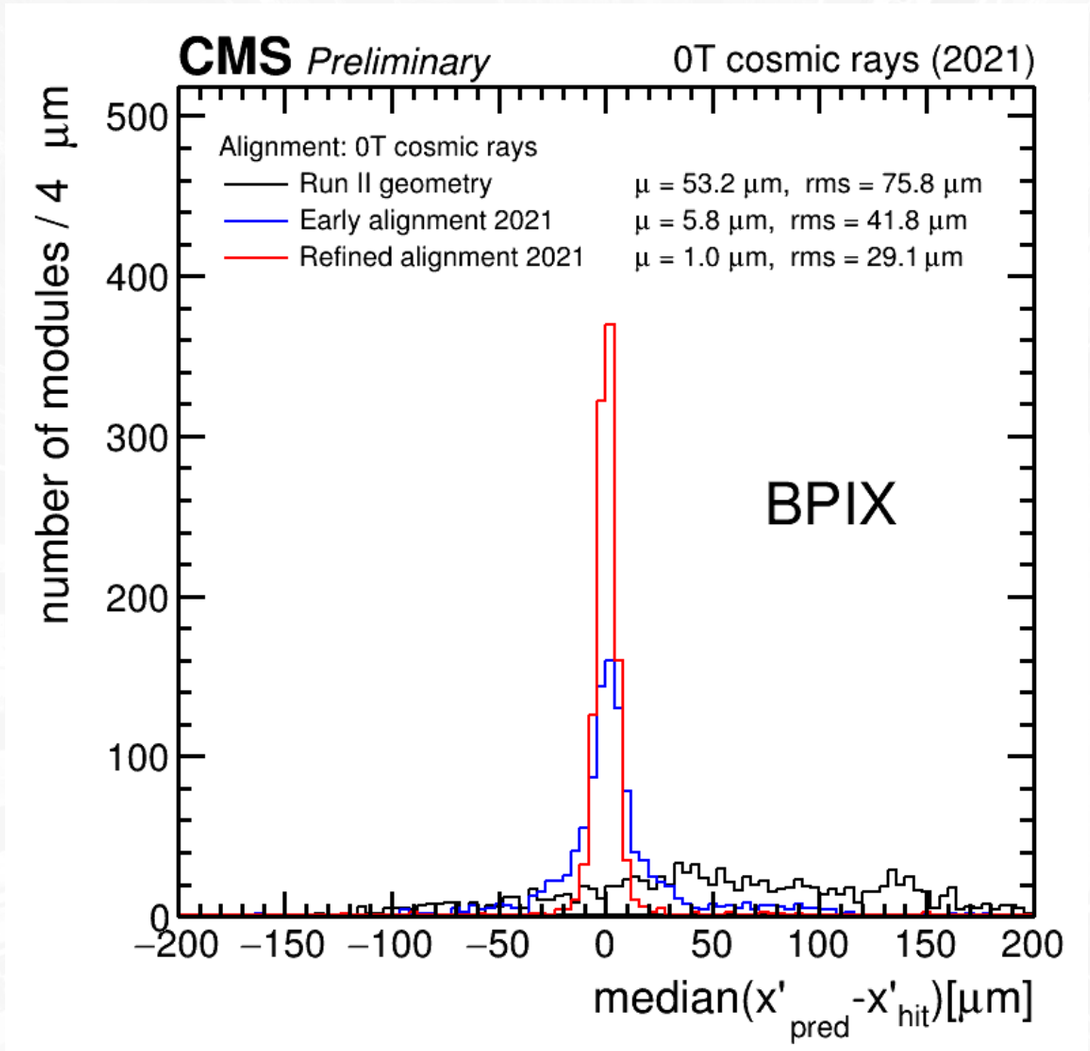
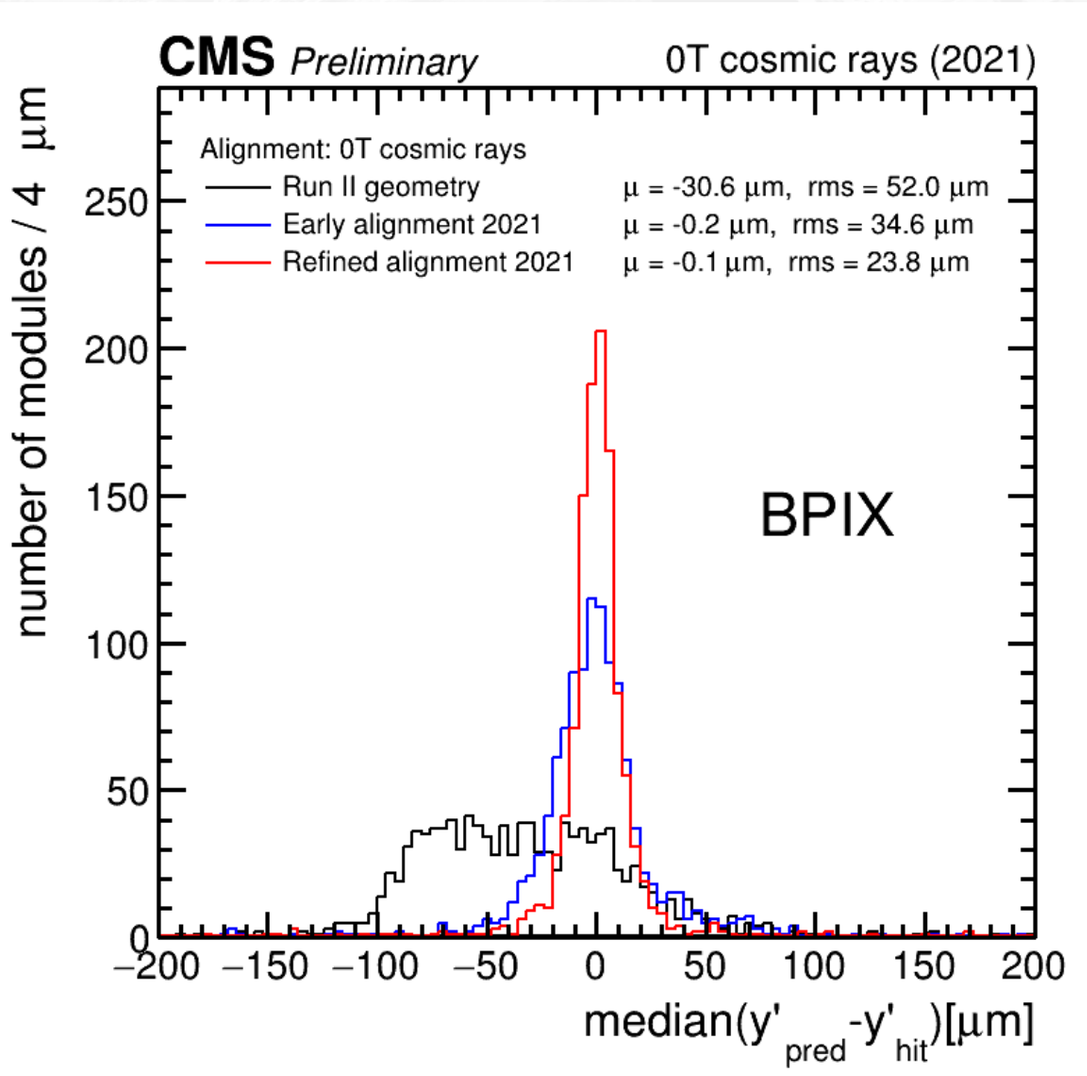


# GPU deployment @HLT

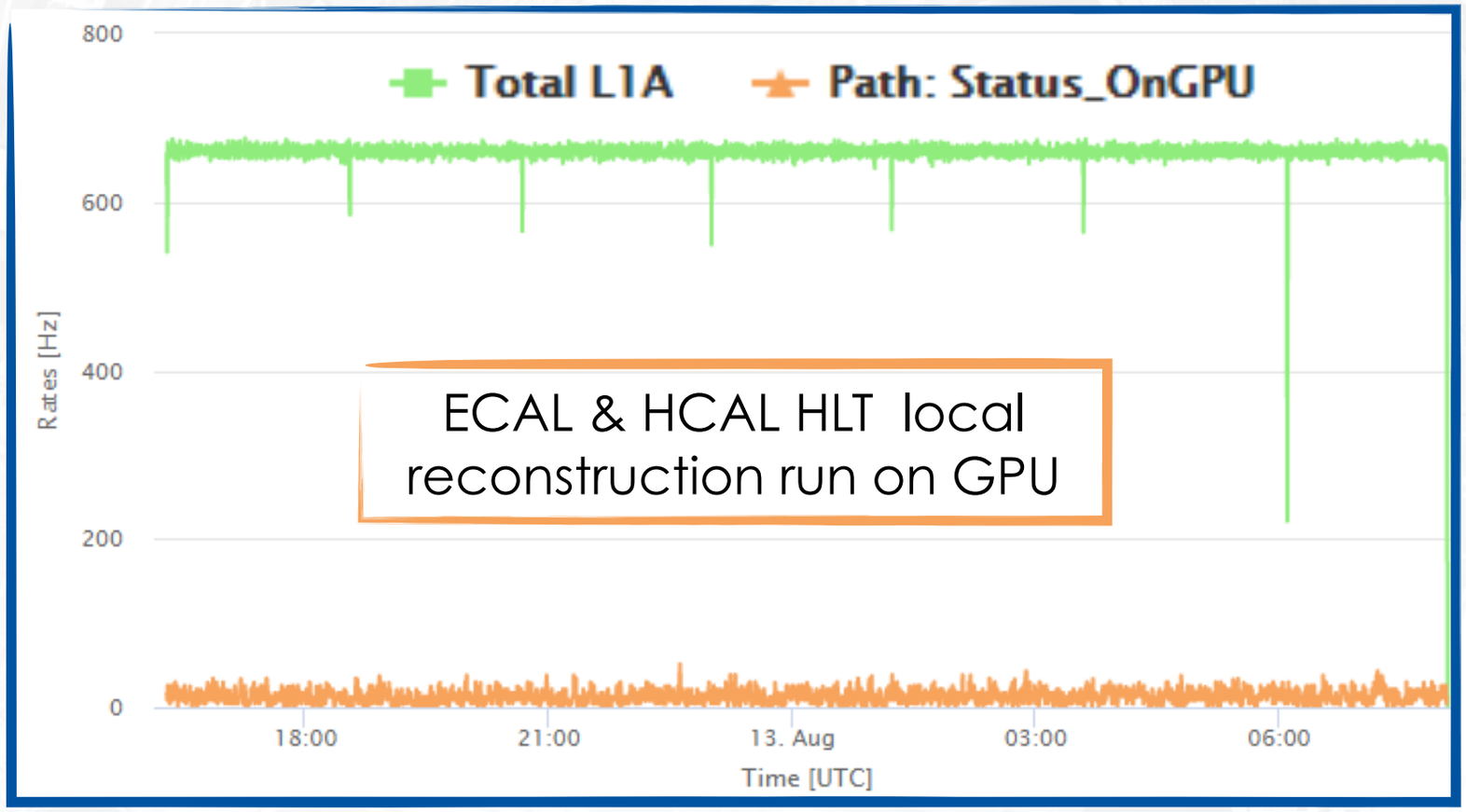
- Previously CMS has demonstrated **ECAL, HCAL and pixel local reco offloaded to GPUs** ( ~25-30% of the menu)

- Now **integrated necessary code to run GPU algorithms** in standard release

- **Completed the upgrade** of infrastructure to deploy GPU based menus at PT5

  - currently two out of 153 nodes are equipped with an NVIDIA T4 GPU

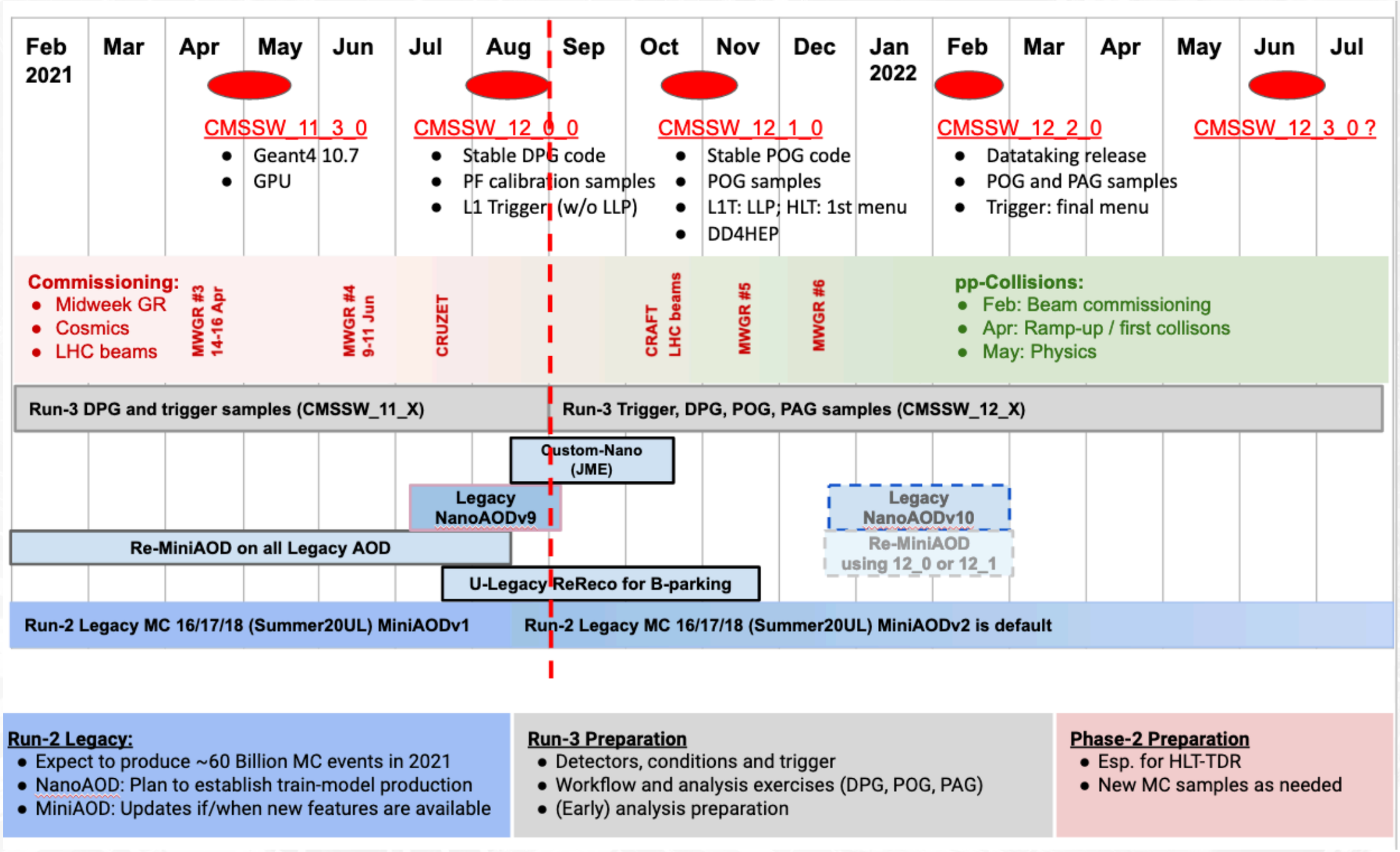
  - ability to run same config on CPU only and CPU+GPU nodes




- System commissioned and GPU enabled menus **run routinely at PT5**

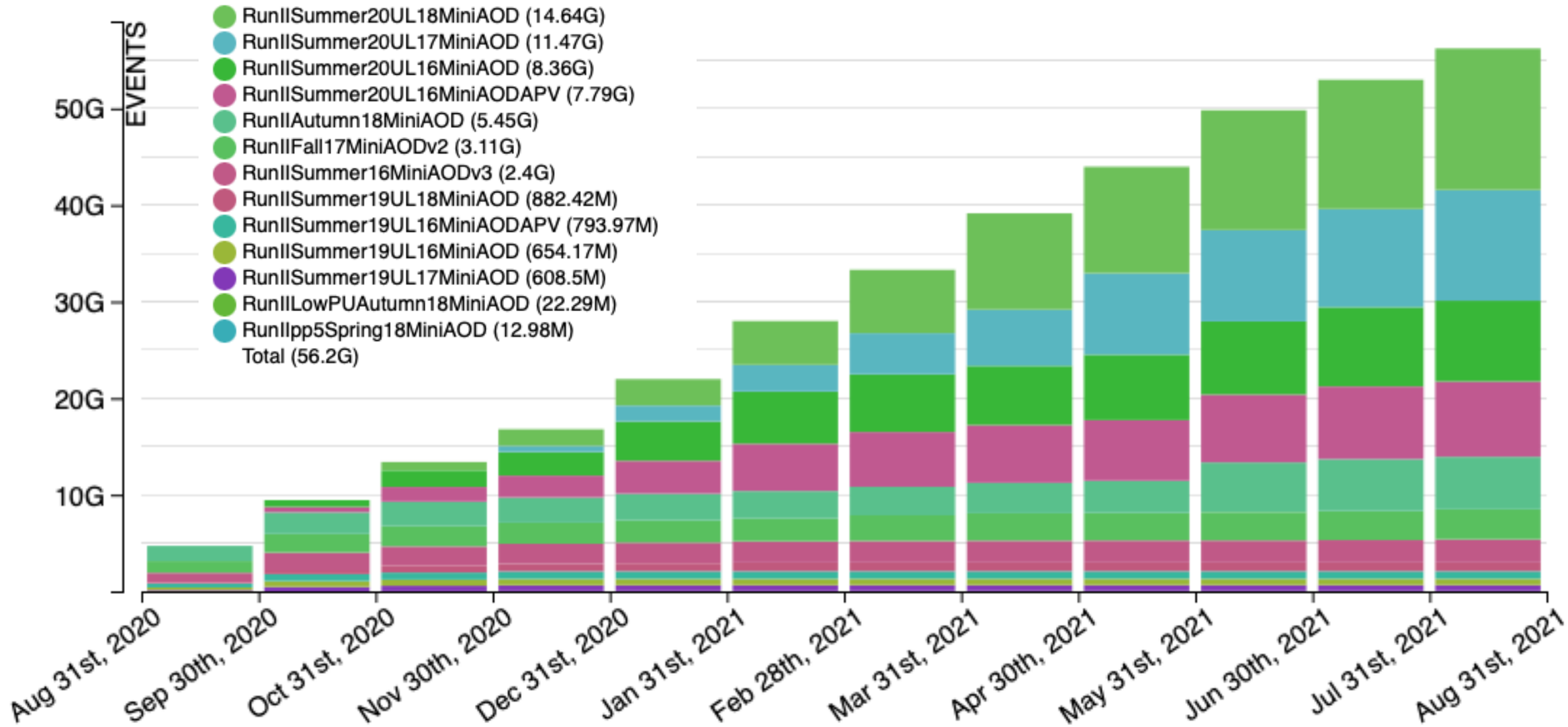
# Computing operations and data processing

# Release and production plan until mid 2022



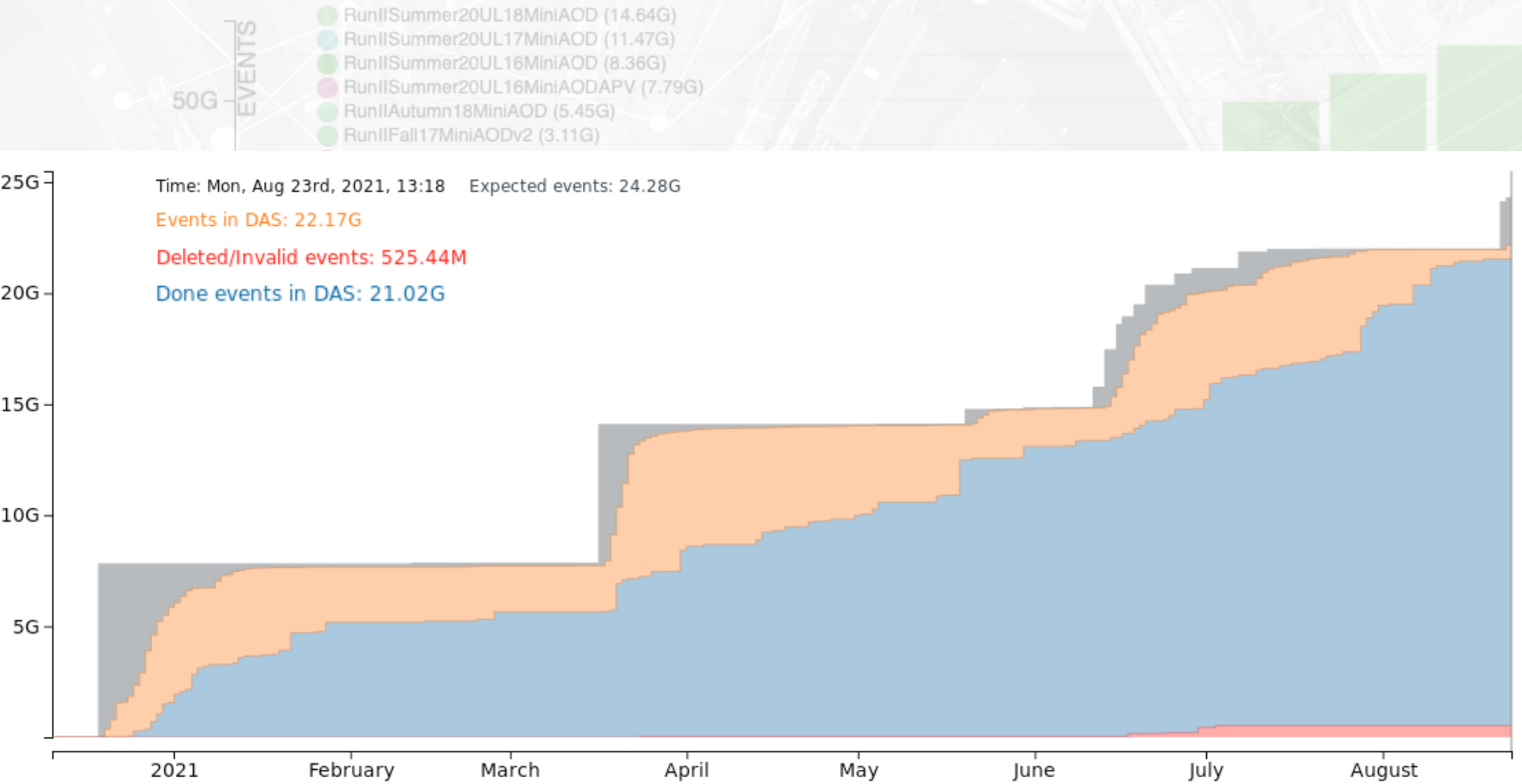

- CMSSW 12_0_0 is the first Python 3 only release

# Simulation and Re-Processing



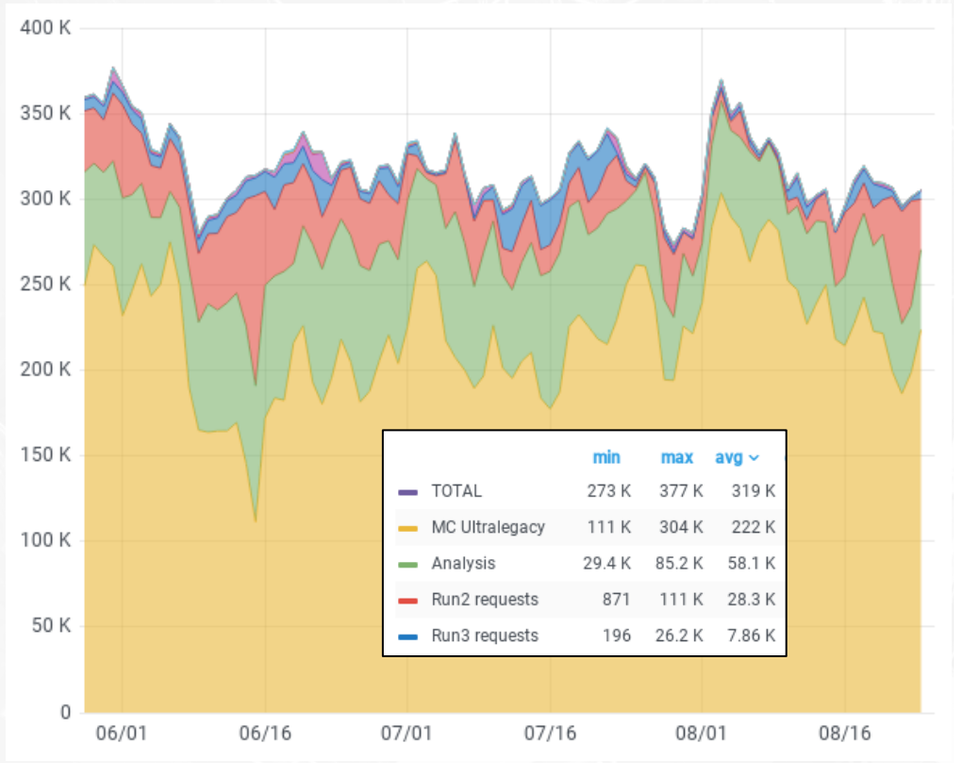

- **Simulation production:**
  **>50B unique Run II MC events** produced in past year

# Simulation and Re-Processing




- **Analysis Run II data re-processing:** data nearly complete, MC 85%, B-parking recently submitted
- **Physics Object Group Run III** samples starting now

# High Performance Computing

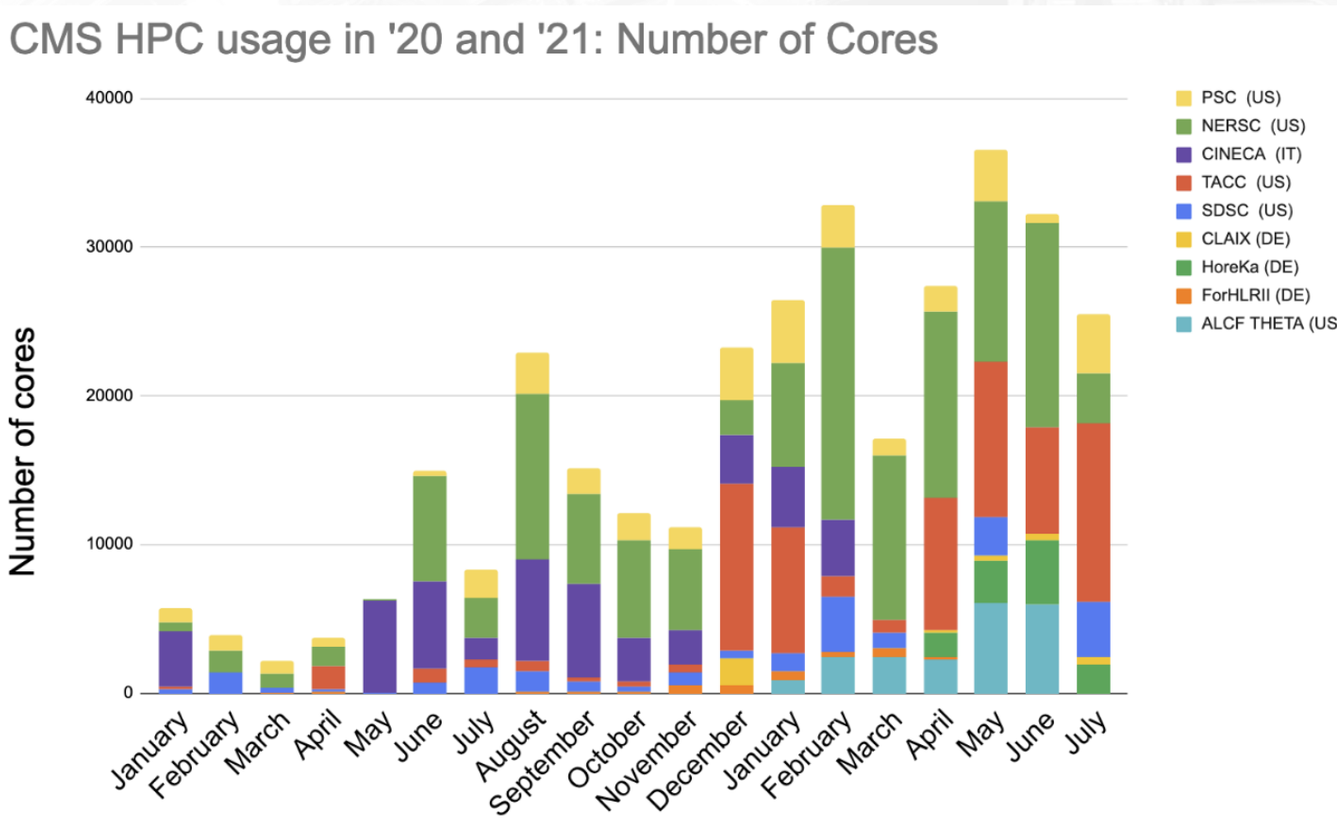



- Using full **CPU capacity** at disposal, **boosted by High Performance Computers**

- **Legacy Monte Carlo generation** dominating the job mixture

- Excellent usage of HPC, steadily increasing

- **HCP Average capacity tripled** in the first 7 months of 2021 relative to 2020



# *Physics analyses and publications*

# Major 2021 summer conferences

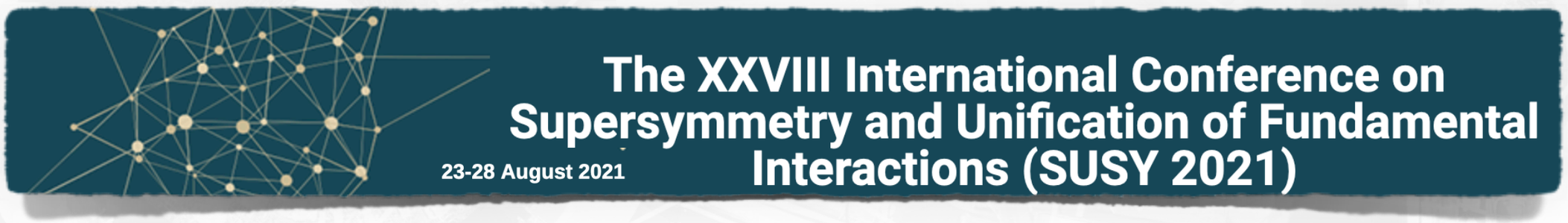
6/6


52 talks (plenary and parallel) - 25 posters - **15 New Results**

26/7


53 talks (plenary and parallel) - 35 posters - **26 New Results**

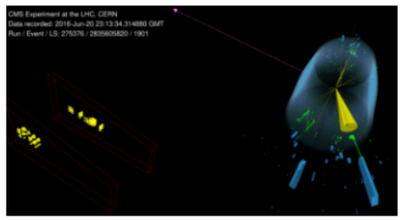
23/8




25 talks (plenary and parallel) - **4 New Results**

# Physics communications

Many physics briefings were presented since last LHCC, for the LHCP, EPS, and SUSY conferences: [link here]

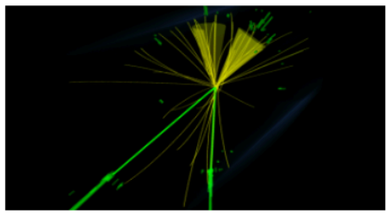


A NEW WINDOW INTO THE SHADOW WORLD: EXOTIC PARTICLE DECAYS IN THE MUON DETECTORS

27 AUG 2021

A new window into the shadow world: exotic particle decays in the muon detectors 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...

READ MORE



LIVE LONG AND PROSPER: SEARCHING FOR THE LONG-LIVED RELATIVES OF THE HIGGS BOSON

16 AUG 2021

Live long and prosper: Searching for the long-lived relatives of the Higgs boson A recent result from CMS searches for long-lived particles through the so-called "Higgs portal" in ways never done before. For about a decade now the CMS experiment at...

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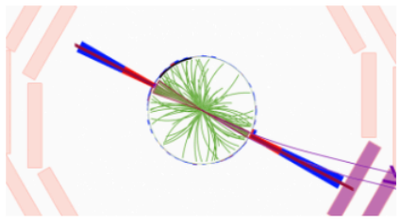

ANY MORE HIGGSES WE SHOULD KNOW ABOUT?

04 AUG 2021

This year marked the ninth anniversary of the discovery of the Higgs boson; the Standard Model particle linked to the mystery of creating the mass of all the other fundamental particles through the so-called Higgs mechanism. While a single Higgs...

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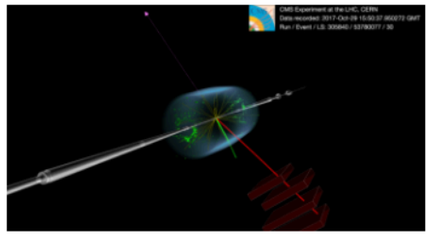
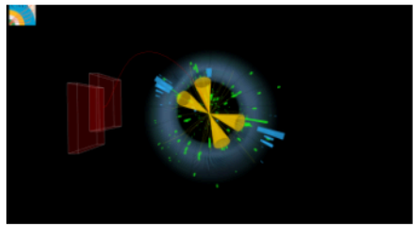


SEARCHING FOR THE DARK SIDE OF THE UNIVERSE

02 AUG 2021

Could you imagine what the dark part of the universe is like? The Standard Model of Particle Physics explains matter at the subatomic level and the related phenomena such as interactions and forces between the subatomic particles. Still, we already...

READ MORE

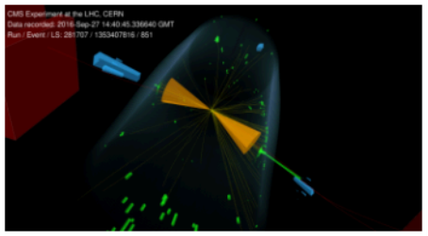


THE FOUR BEAUTIES IN THE TALE OF TWO HIGGSES

30 JUL 2021

The interaction of the Higgs boson with its own field leads to its mass generation. Since the Higgs boson mass has already been measured, the study of the Higgs pair production at the LHC reveals directly the strength of the Higgs self coupling λHHH...

READ MORE

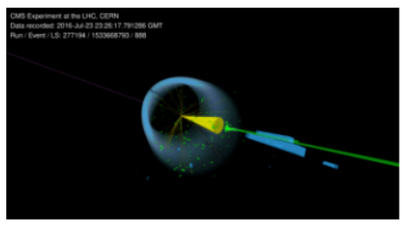


JETS-OF-ALL-TRADES: CONSTRAINING STANDARD MODEL AND BEYOND

25 JUL 2021

For the first time, CMS physicists extract the fundamental parameters of QCD together with constraints on the New Physics. Any tiny failure of the Standard Model to explain data behaviour is a possible window for the New Physics. An example is...

READ MORE

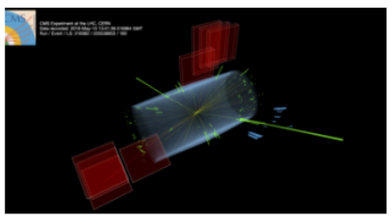


A TALE OF TWO COLLIDERS AND THE UNRIVALLED PRECISION ON THE Z INVISIBLE WIDTH

19 JUL 2021

The most powerful particle collider in the world, the Large Hadron Collider (LHC), was built in the 27 km tunnel originally excavated for the highest energy electron-positron collider ever built, LEP. As an extraordinarily sensitive machine, LEP was...

READ MORE



USING THE GOLDEN DECAY CHANNEL TO UNDERSTAND THE PRODUCTION OF THE HIGGS BOSON

10 JUN 2021

Using the golden decay channel to understand the production of the Higgs boson The standard model of particle physics is currently the best way to describe interactions of fundamental particles that make up our Universe. It has been tested over many...

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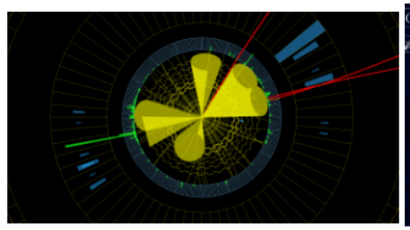
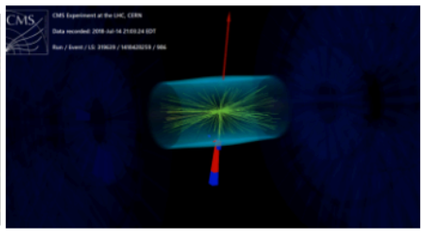


WHAT DOES THE DECAY OF A BOTTOM QUARK LOOK LIKE?

09 JUN 2021

What does the decay of a bottom quark look like? Fragmentation, also known as hadronization, is when particles that contain quarks or gluons create other particles via the strong interaction. The fragmentation process cannot be exactly calculated...

READ MORE

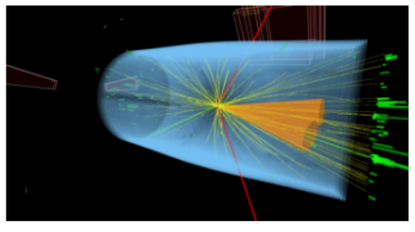


A SHOT IN THE DARK: CAN JETS RECOIL AGAINST DARK MATTER?

07 JUN 2021

A shot in the dark: Can jets recoil against Dark Matter? In their 2020 hit single 'A Shot in the Dark' the rock band AC/DC got it right in many ways: "A shot in the dark Make you feel alright A shot in the dark All through the whole night" The...

READ MORE

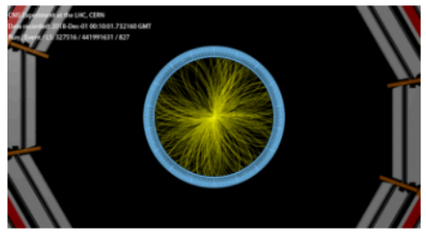


USING MACHINE LEARNING TO IMPROVE THE DETECTION OF NEW PHYSICS IN THE INTERACTIONS OF THE TOP QUARK

04 JUN 2021

Using machine learning to improve the detection of new physics in the interactions of the top quark Although our theory describing the interactions between fundamental particles is exceptionally successful, it has weaknesses. You may have heard,...

READ MORE



EXPLORING THE PHYSICS PROCESSES INSIDE THE HOTTEST MATTER IN THE UNIVERSE

04 JUN 2021

Quarks are elementary particles in the Standard Model and the building blocks of the protons and neutrons in atoms. The dominant force between quarks is the strong interaction. Gluons are the force carriers of the strong interaction, and one thing...

READ MORE

# Summer 2021 publication activity

## TOP

| | | | | |
|---|---|---|---|---|
| 1020 | TOP-19-009 | **Measurement of the top quark mass using events with a single reconstructed top quark in pp collisions at $\sqrt{s} = 13$ TeV** | Submitted to JHEP | 24 August 2021 |
| 1019 | TOP-20-001 | **Measurement of differential $\mathrm{t\bar{t}}$ production cross sections in the full kinematic range using lepton+jets events from proton-proton collisions at $\sqrt{s} = 13$ TeV** | Submitted to PRD | 5 August 2021 |
| 1018 | TOP-21-001 | **Probing effective field theory operators in the associated production of top quarks with a Z boson in multilepton final states at $\sqrt{s} = 13$ TeV** | Submitted to JHEP | 29 July 2021 |
| 1012 | TOP-18-010 | **Measurement of the inclusive and differential $\mathrm{t\bar{t}}\gamma$ cross sections in the single-lepton channel and EFT interpretation at $\sqrt{s} = 13$ TeV** | Submitted to JHEP | 3 July 2021 |

## HIG

| | | | | |
|---|---|---|---|---|
| 1015 | HIG-20-015 | **Measurement of the inclusive and differential Higgs boson production cross sections in the decay mode to a pair of $\tau$ leptons in pp collisions at $\sqrt{s} = 13$ TeV** | Submitted to PRL | 23 July 2021 |
| 1005 | HIG-20-014 | **Search for a heavy Higgs boson decaying into two lighter Higgs bosons in the $\tau\tau\mathrm{bb}$ final state at 13 TeV** | Submitted to JHEP | 18 June 2021 |

## SMP

| | | | | |
|---|---|---|---|---|
| 1007 | SMP-20-016 | **Measurement of the electroweak production of $\mathrm{Z}\gamma$ and two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV and constraints on anomalous quartic gauge couplings** | Submitted to PRD | 21 June 2021 |
| 1010 | SMP-20-012 | **Measurements of the electroweak diboson production cross sections in proton-proton collisions at $\sqrt{s} = 5.02$ TeV using leptonic decays** | Submitted to PRL | 2 July 2021 |

## BPH

| | | | | |
|---|---|---|---|---|
| 1011 | BPH-18-003 | **Measurement of prompt open-charm production cross sections in proton-proton collisions at $\sqrt{s} = 13$ TeV** | Submitted to JHEP | 3 July 2021 |

# Summer 2021 publication activity

## EXO

| | | | | |
|---|---|---|---|---|
| 1017 | EXO-20-004 | **Search for new particles in events with energetic jets and large missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV** | Submitted to JHEP | 27 July 2021 |
| 1013 | EXO-20-015 | **Search for long-lived particles decaying in the CMS endcap muon detectors in proton-proton collisions at $\sqrt{s} = 13$ TeV** | Submitted to PRL | 10 July 2021 |
| 1006 | EXO-20-001 | **Search for $\mathrm{W}\gamma$ resonances in proton-proton collisions at $\sqrt{s} = 13$ TeV using hadronic decays of Lorentz-boosted W bosons** | Submitted to PLB | 19 June 2021 |

## SUS

| | | | | |
|---|---|---|---|---|
| 1016 | SUS-20-003 | **Search for chargino-neutralino production in events with Higgs and W bosons using 137 fb$^{-1}$ of proton-proton collisions at $\sqrt{s} = 13$ TeV** | Submitted to JHEP | 26 July 2021 |
| 1014 | SUS-20-002 | **Combined searches for the production of supersymmetric top quark partners in proton-proton collisions at $\sqrt{s} = 13$ TeV** | Submitted to EPJC | 22 July 2021 |
| 1009 | SUS-19-012 | **Search for electroweak production of charginos and neutralinos in proton-proton collisions at $\sqrt{s} = 13$ TeV** | Submitted to JHEP | 27 June 2021 |

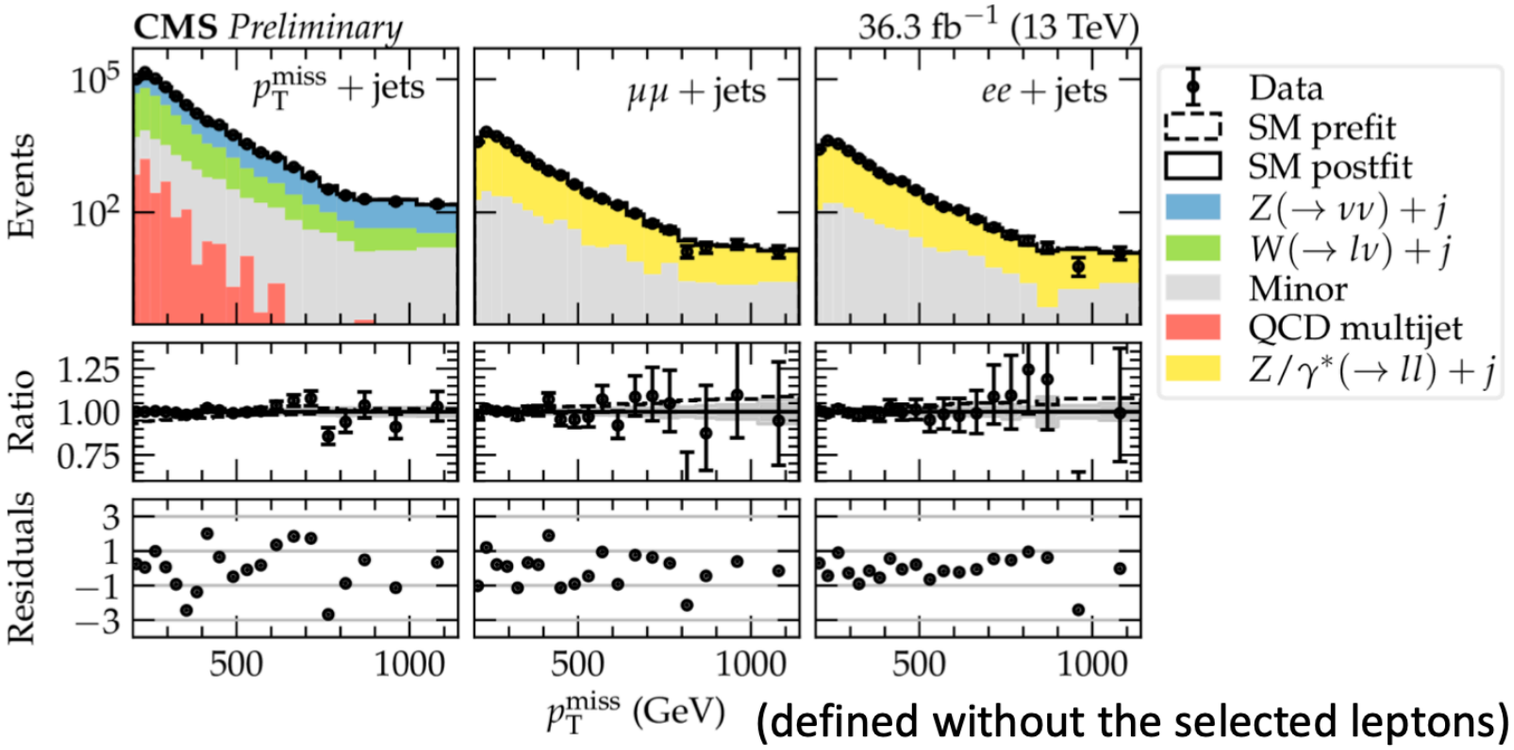
## HIN

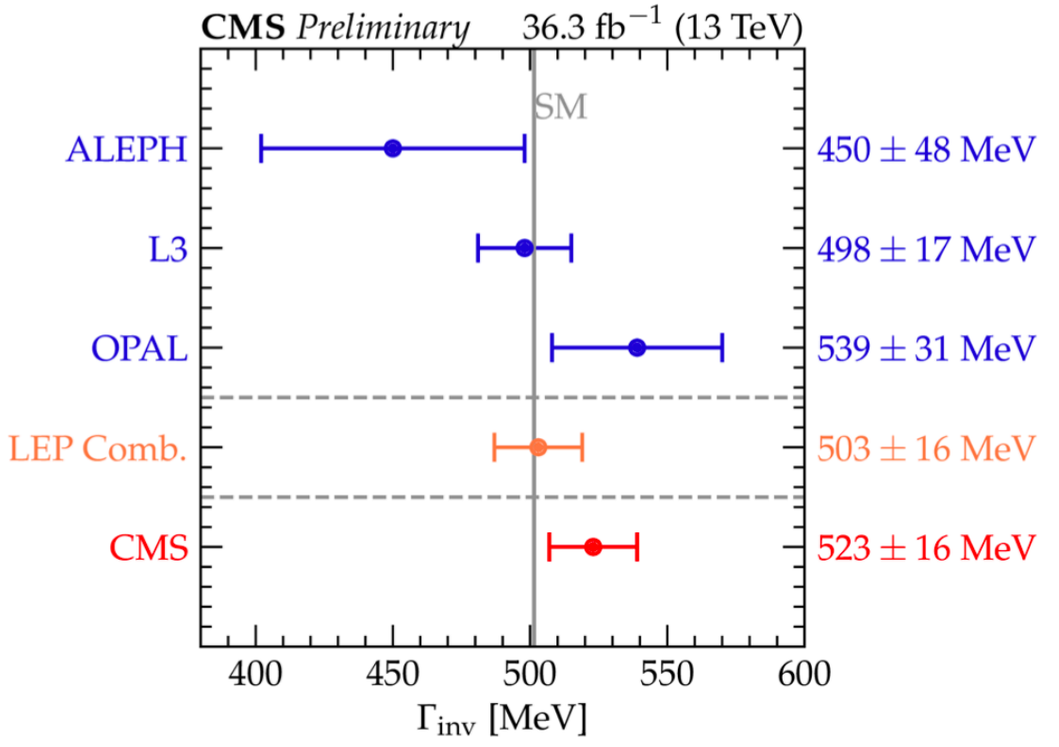
| | | | | |
|---|---|---|---|---|
| 1008 | HIN-19-007 | **Fragmentation of jets containing a prompt $\mathrm{J}/\psi$ meson in PbPb and pp collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV** | Submitted to PLB | 23 June 2021 |

# Measurement of the Z invisible width

- Z invisible width extracted from ratio of **measured cross sections of Z(vv) +jets to Z(ll )+jets**:

$$\Gamma(Z \to \nu\bar{\nu}) = \frac{\sigma(Z+\text{jets})\mathcal{B}(Z \to \nu\bar{\nu})}{\sigma(Z+\text{jets})\mathcal{B}(Z \to \ell\ell)}\Gamma(Z \to \ell\ell)$$




(defined without the selected leptons)

- $\Gamma_{inv} = 523 \pm 3\ (\text{stat}) \pm 16\ (\text{syst})$ MeV

- Single **most precise direct measurement of the Z invisible width**
- Similar to combined LEP result

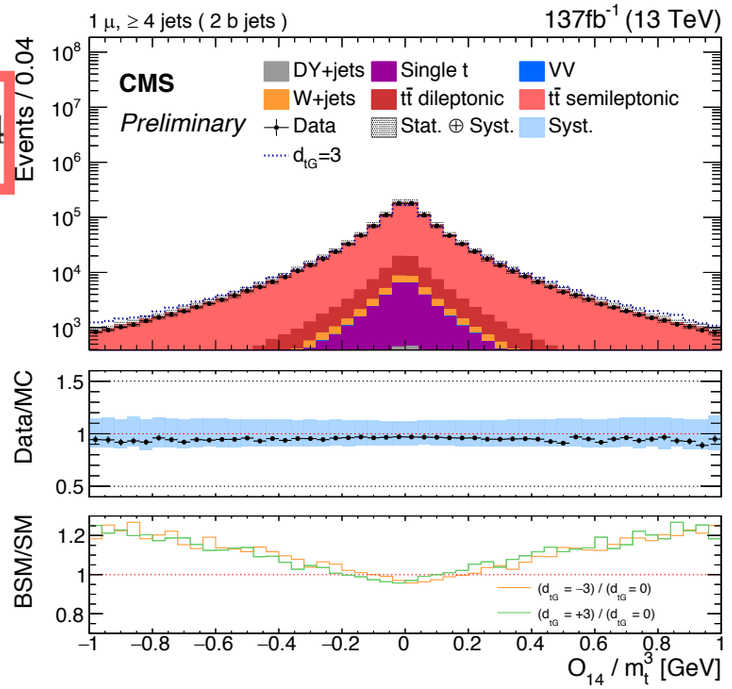
CMS-PAS-SMP-18-014

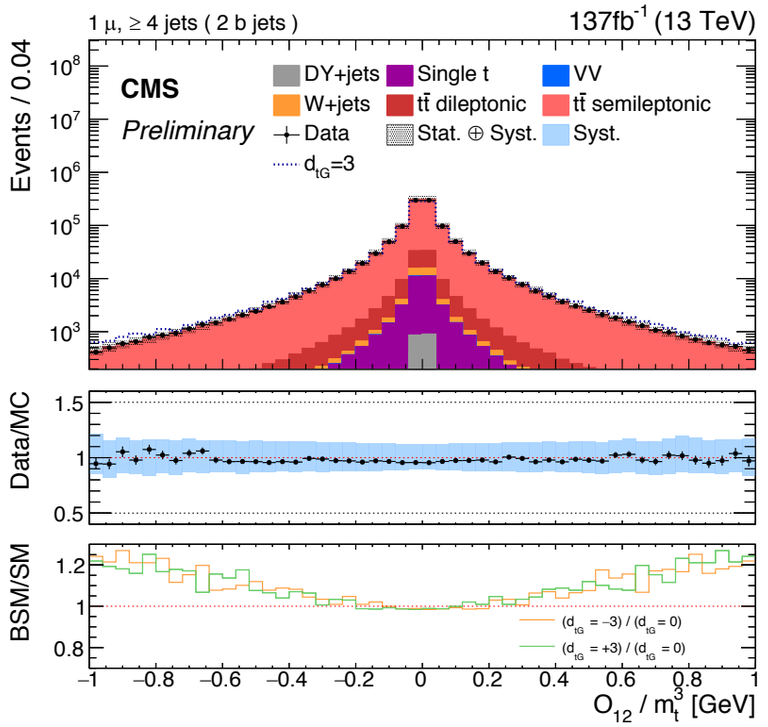
# CP violation in semileptonic top pair events

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

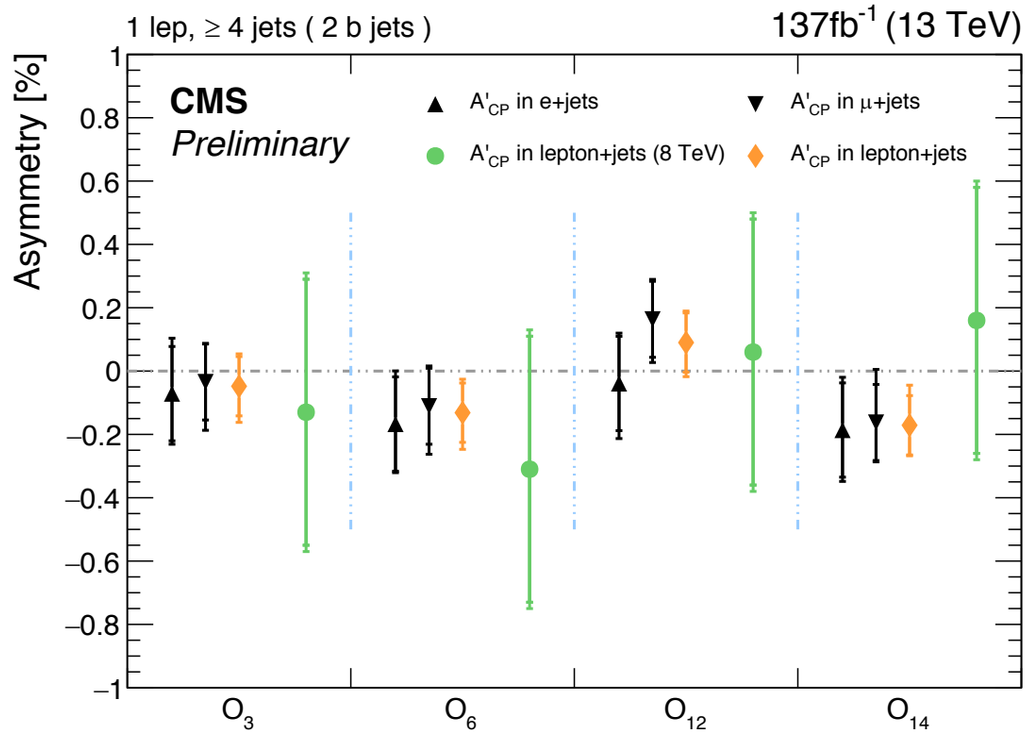
$$A_{CP}(O_i) = \frac{N_{\text{events}}(O_i > 0) - N_{\text{events}}(O_i < 0)}{N_{\text{events}}(O_i > 0) + N_{\text{events}}(O_i < 0)}, i = 3, 6, 12, 14$$

- Lepton + jets final states
- Top candidates reconstructed w/ a $\chi^2$ sorting algorithm



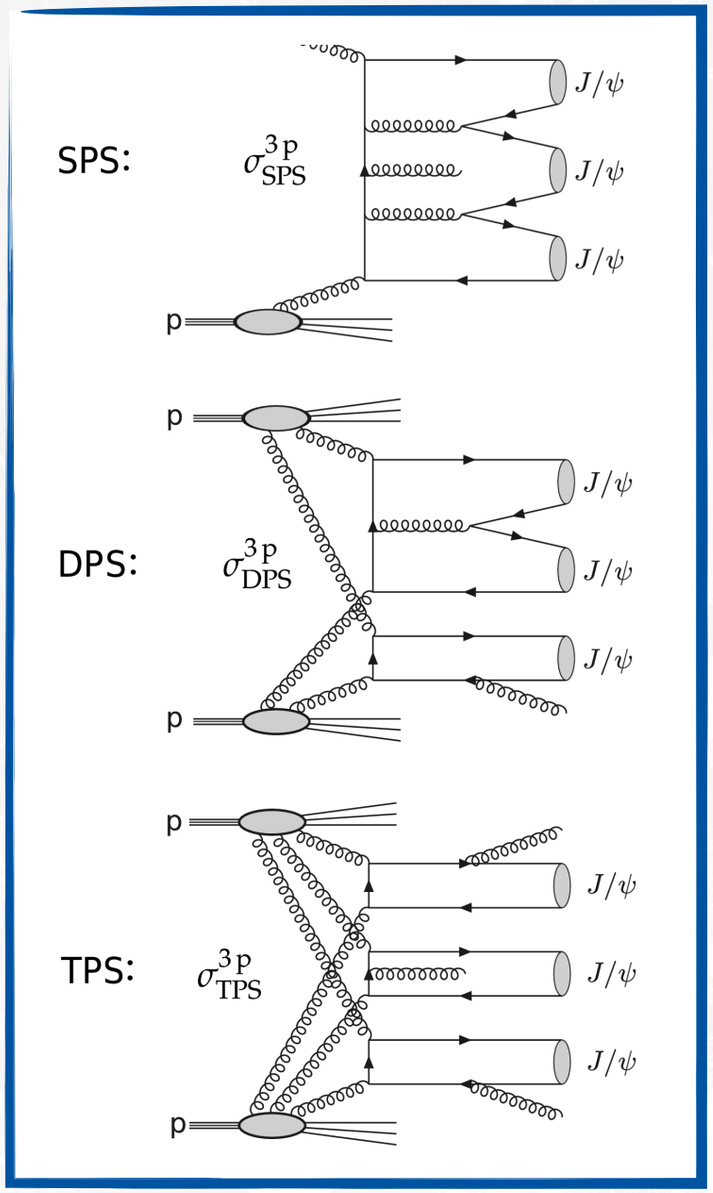

- **All measures asymmetries consistent with 0 indicating no CPV**
- Factor 3 **reduced uncertainties** w.r.t. 8 TeV result



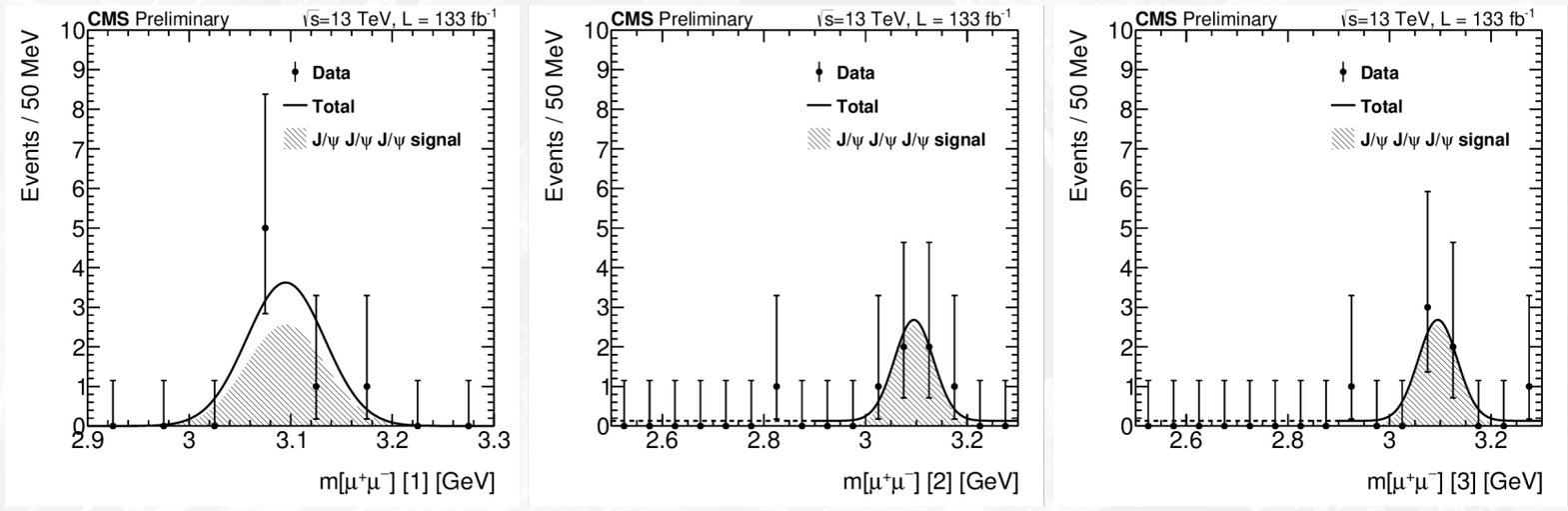

[CMS-PAS-TOP-20-005]

# Observation of triple J/ψ production

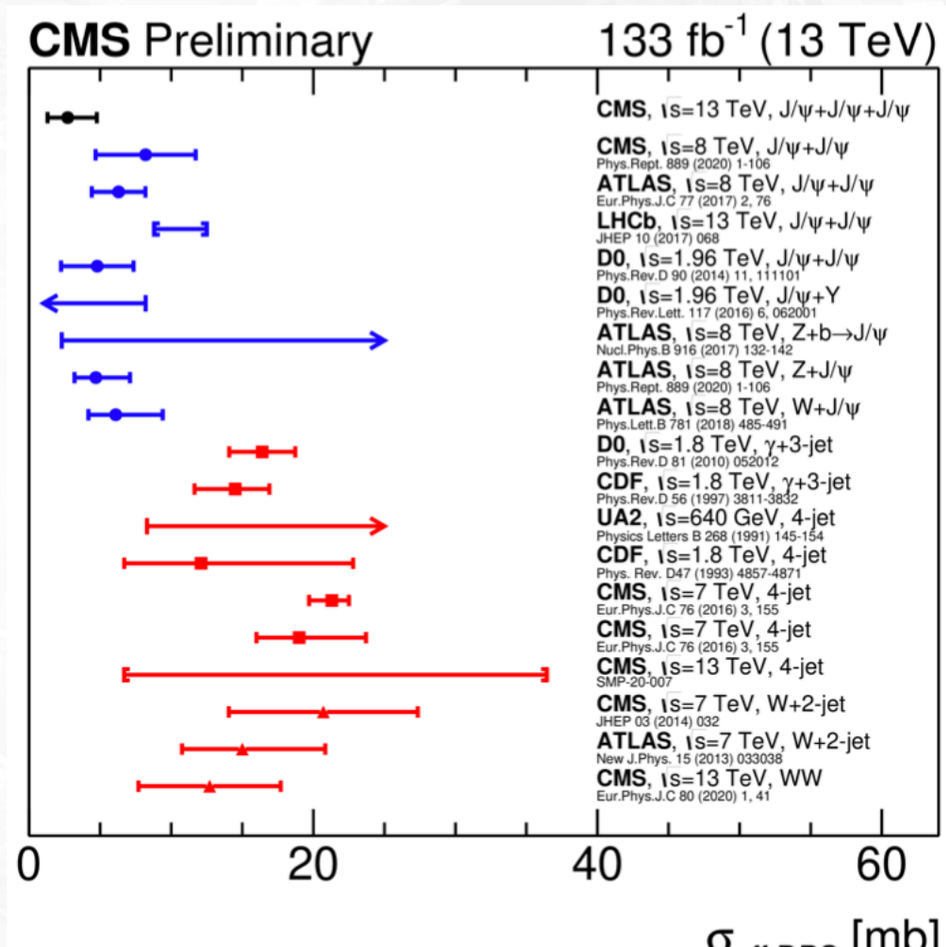
- Golden channel for **double (DPS) and triple parton scattering (TPS)**




Select **6$\mu$ events** consistent with 3 J/ψ decays




- $\sigma(pp \rightarrow 3J/\psi\, X) = 272 \pm 118\ (stat) \pm 16\ (syst)$ fb
- **$\sigma_{eff,DPS}$ = 2.7 ± 1.2 (exp)+1.5 (theo) mb**



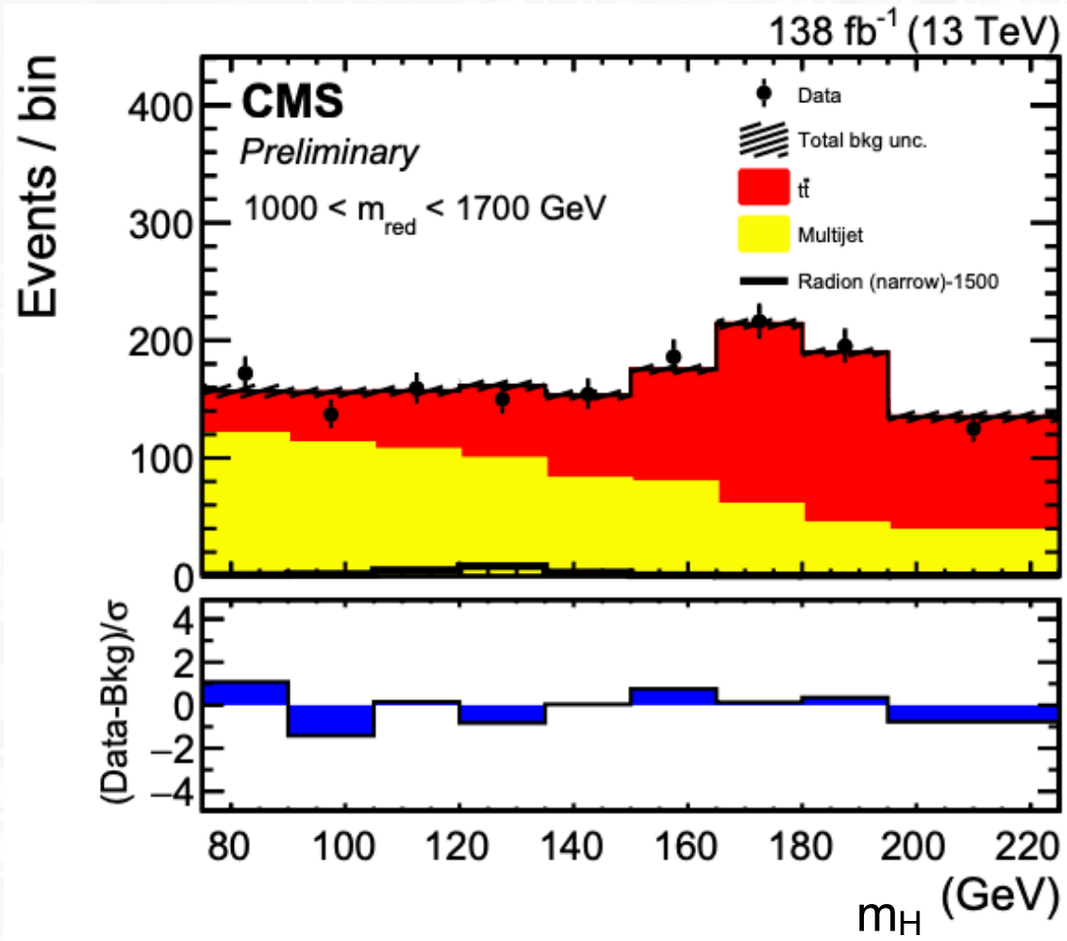

[CMS-PAS-BPH-21-004]

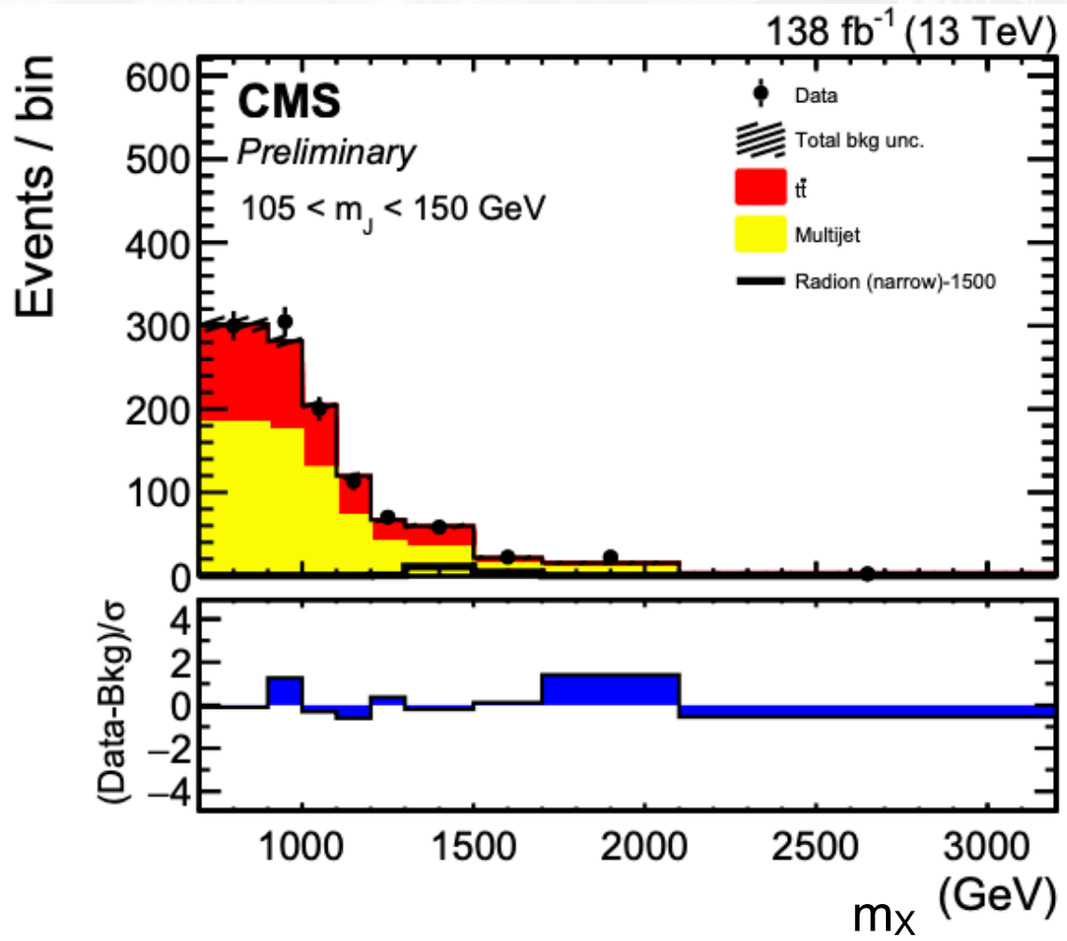
# Heavy resonance X → HH

- **X → HH → 4b** one pair boosted and other boosted or resolved
- **X → HH → bbWW and X → HH → bb$\tau\tau$** with one b-pair boosted

  - Deep neural network used to **tag boosted Higgs decays** and categorize events

  - Signal extracted from a **2D fit to Higgs and X** reconstructed masses



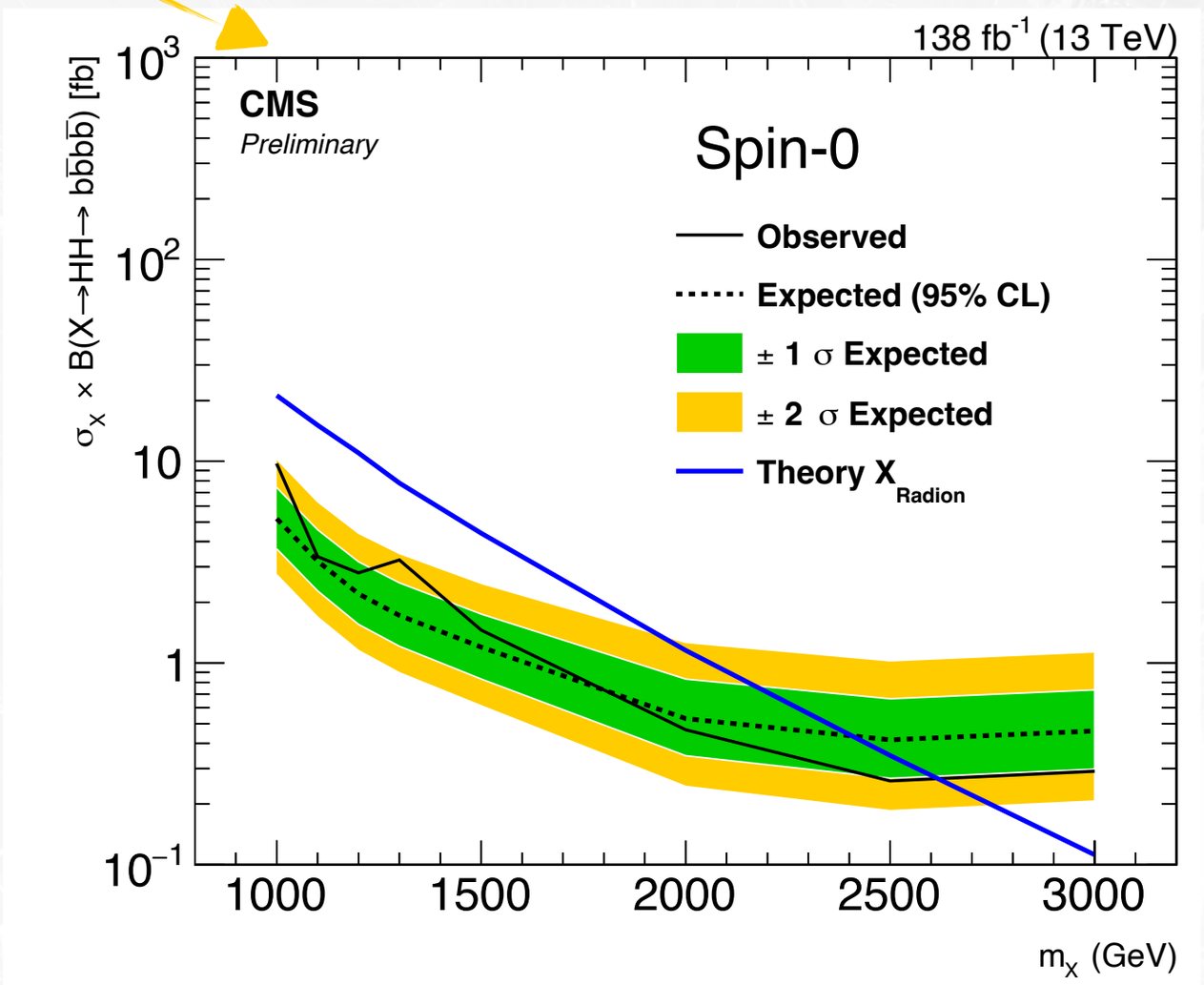



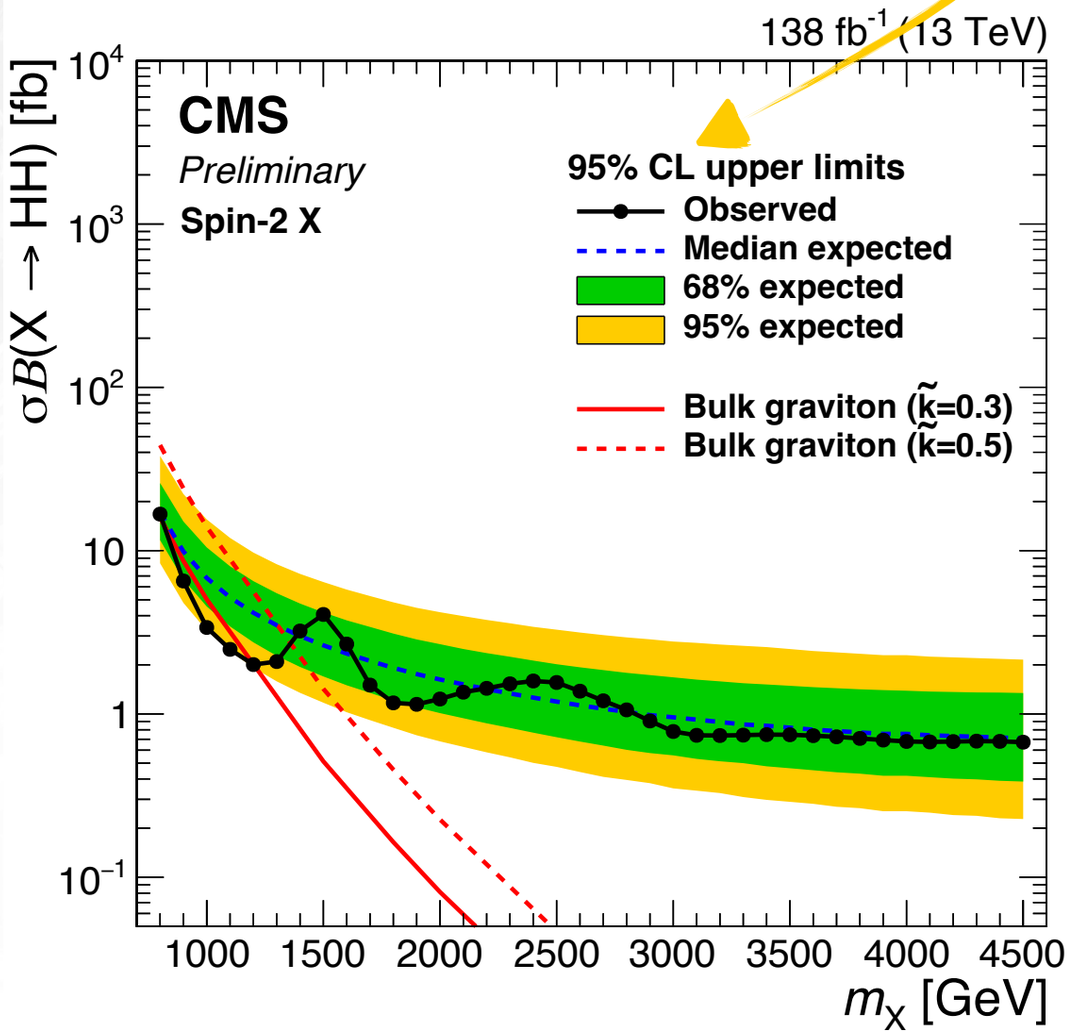

[CMS-PAS-B2G-20-004](#)

[CMS-PAS-B2G-20-007](#)

# Heavy resonance X → HH

- **X → HH → 4b** one pair boosted and other boosted or resolved
- **X → HH → bbWW and X → HH → bb**$\tau\tau$ with one b-pair boosted



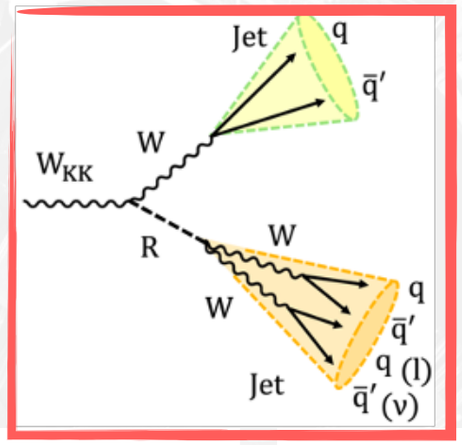

- Sensitivity improved about 6-14 times w.r.t. 2016 only analysis

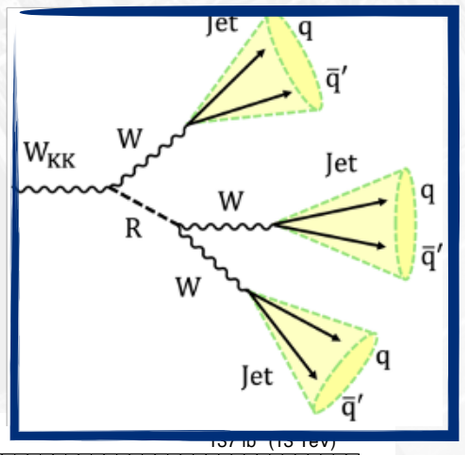
[CMS-PAS-B2G-20-004]

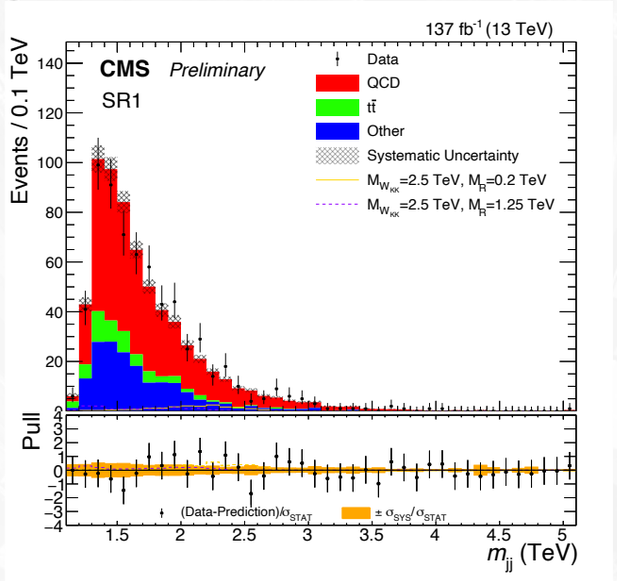
[CMS-PAS-B2G-20-007]

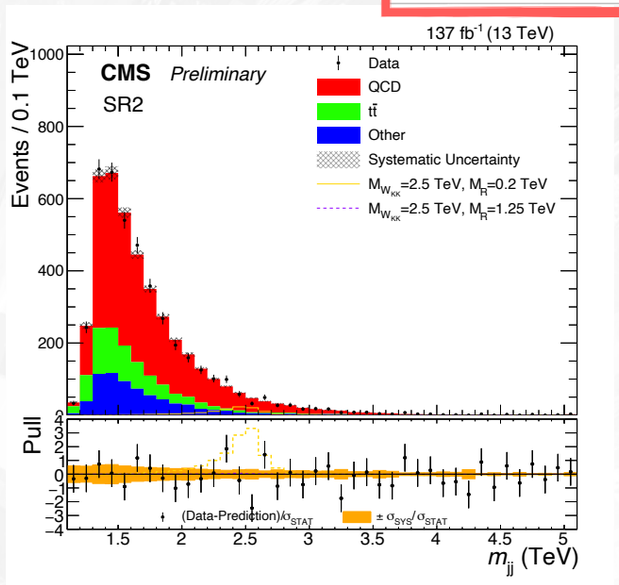
# Three W bosons resonances

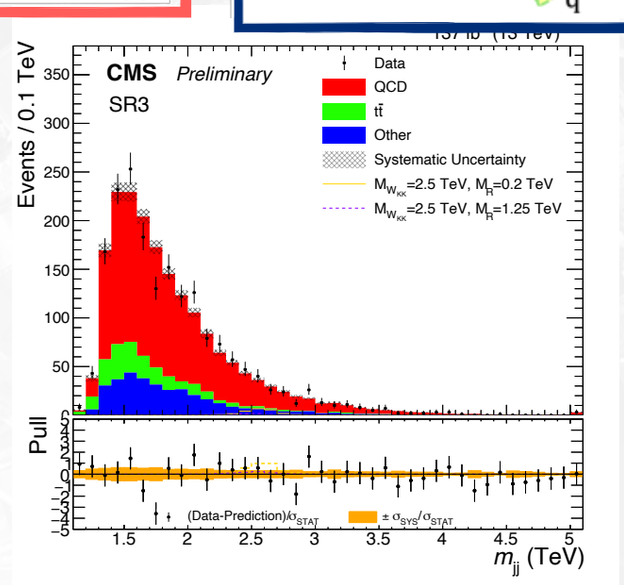
- New resonances decay via a scalar radion R: $\mathbf{W_{KK} \rightarrow WR \rightarrow WWW}$
- **Resolved** & **Merged** fully hadronic decays

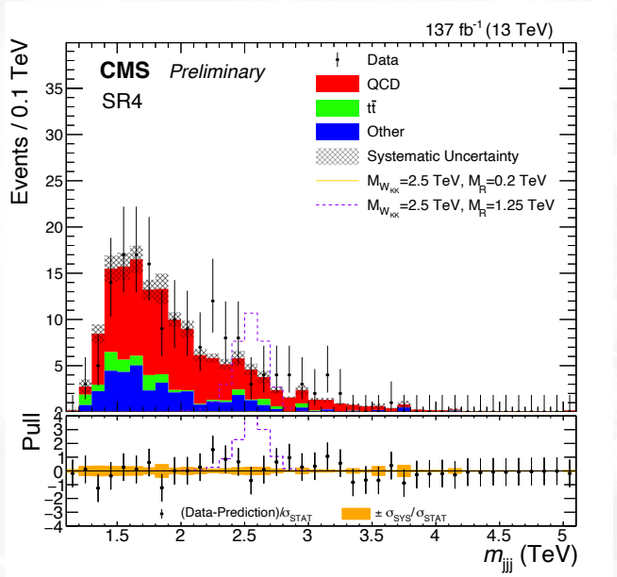


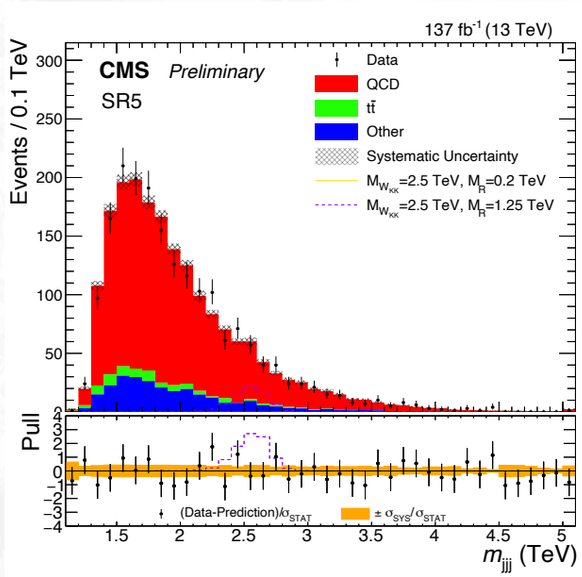



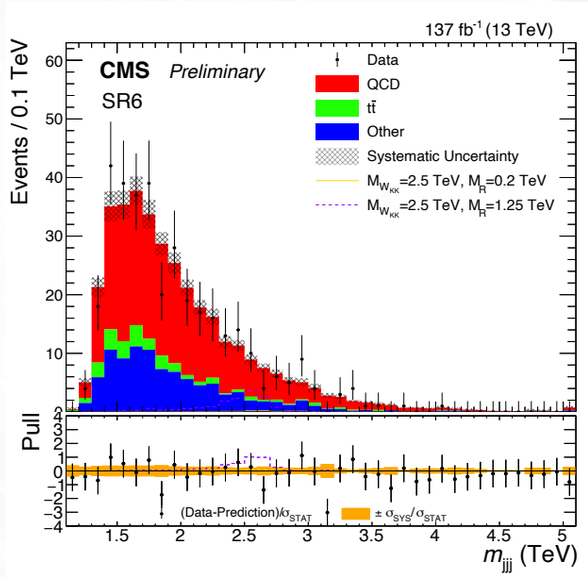



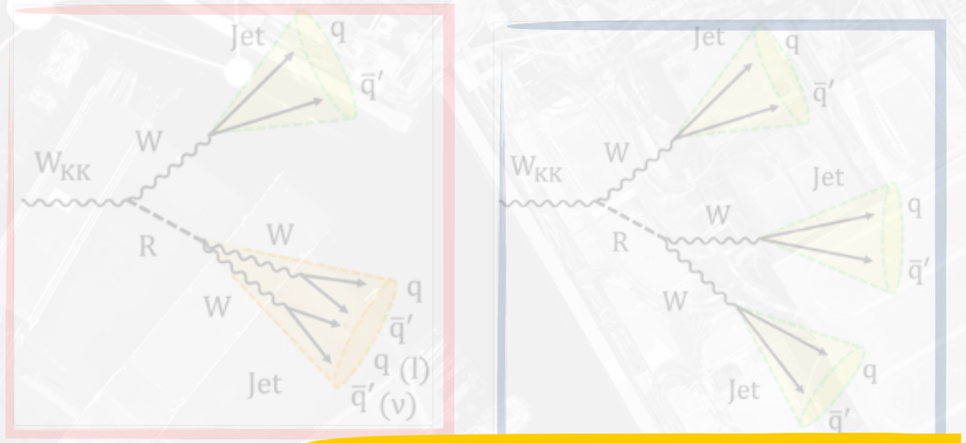




[CMS-PAS-B2G-21-002](#)

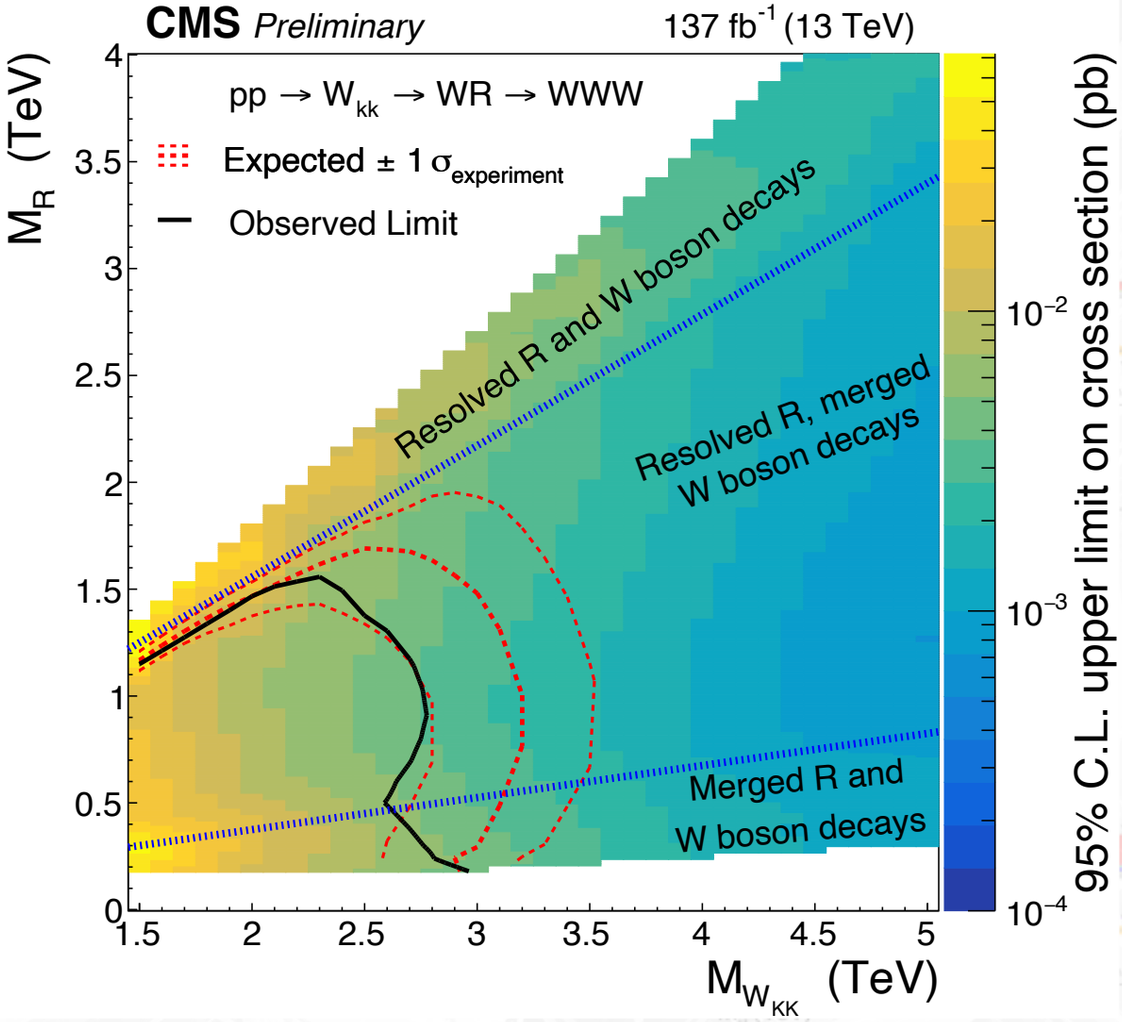
[CMS-PAS-B2G-20-001](#)

# Three W bosons resonances

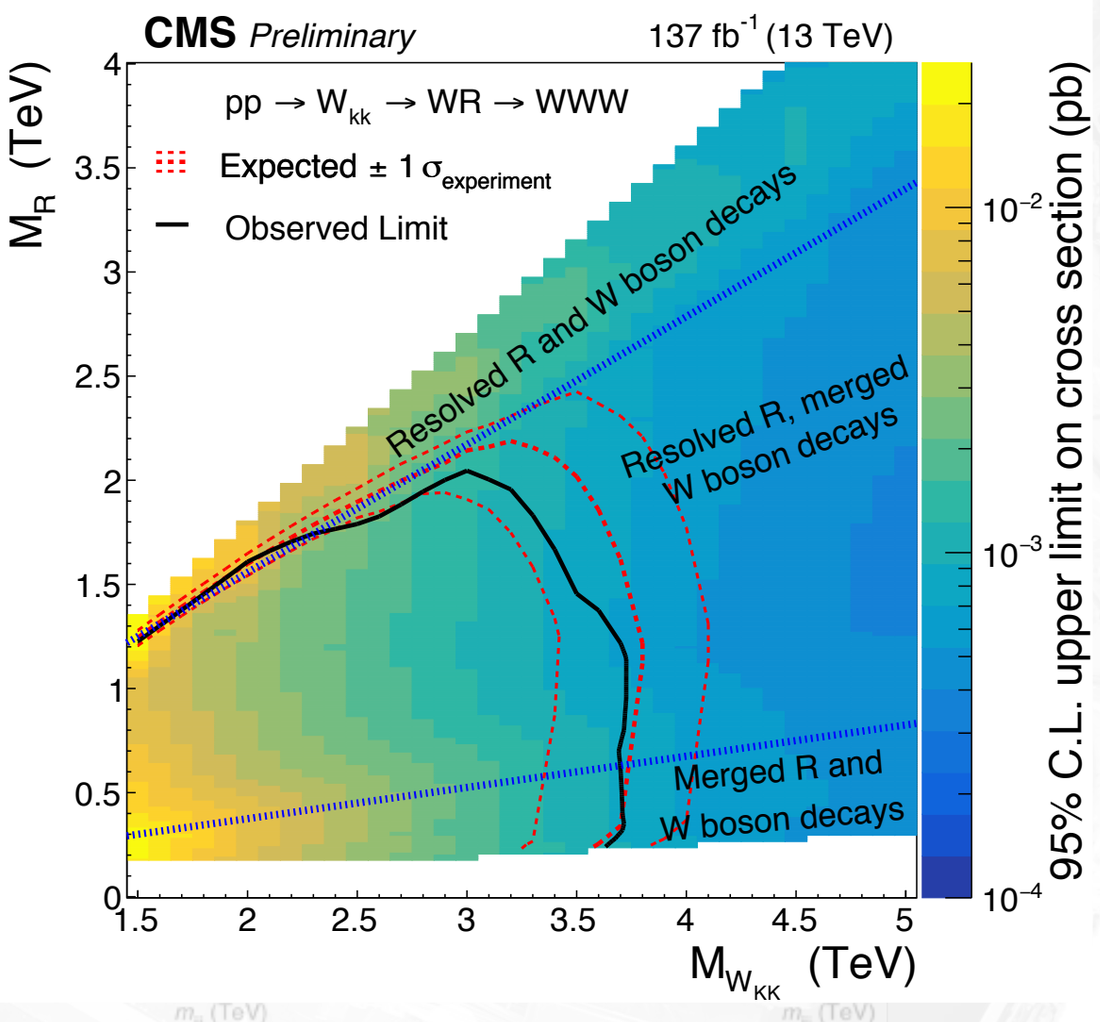
- New resonances decay via a scalar radion R: **$W_{KK} \rightarrow WR \rightarrow WWW$**
- **Resolved** & **Merged** fully hadronic decays




Fully hadronic



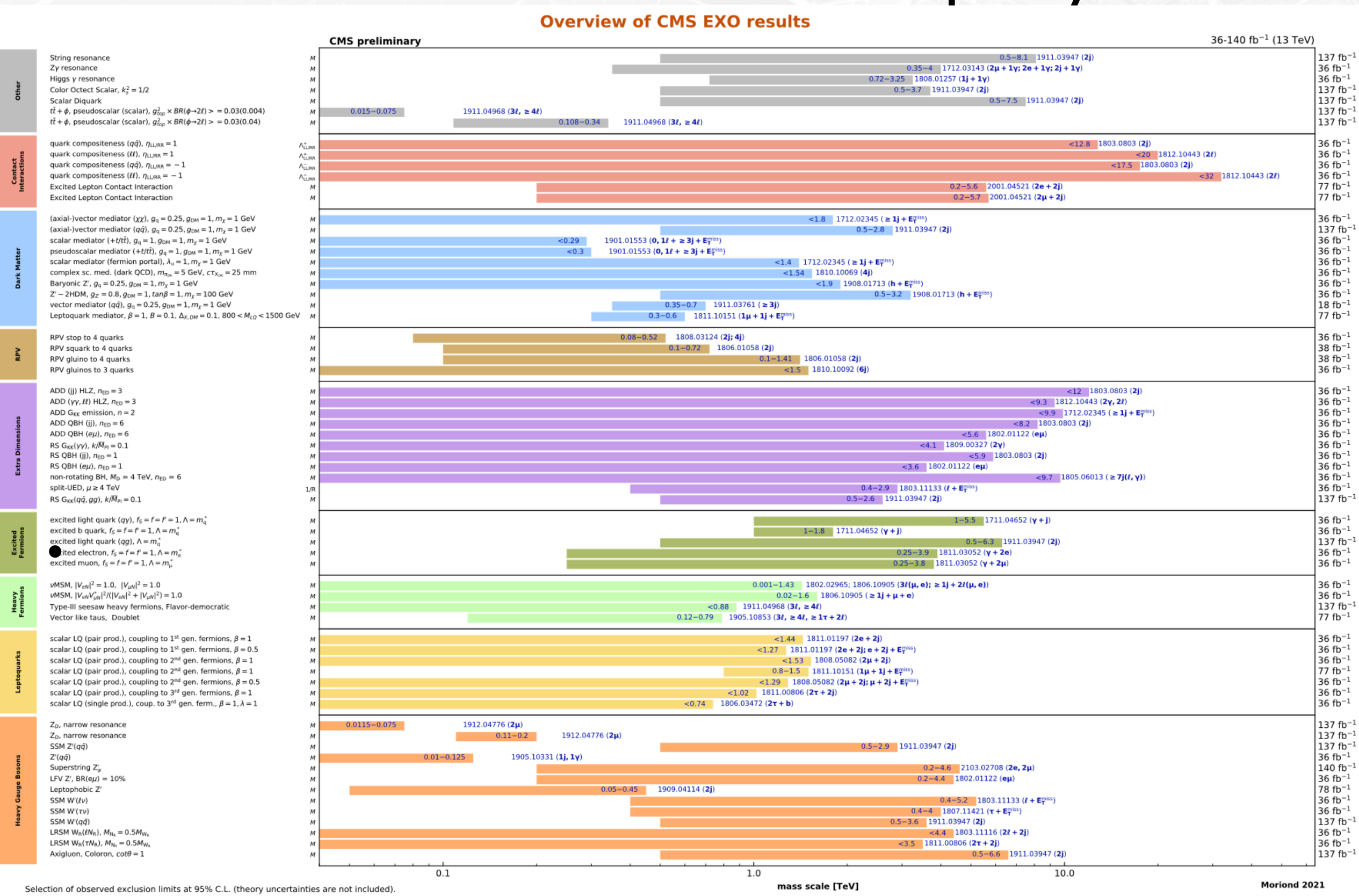

Hadronic+Leptonic




[CMS-PAS-B2G-21-002](#)

[CMS-PAS-B2G-20-001](#)

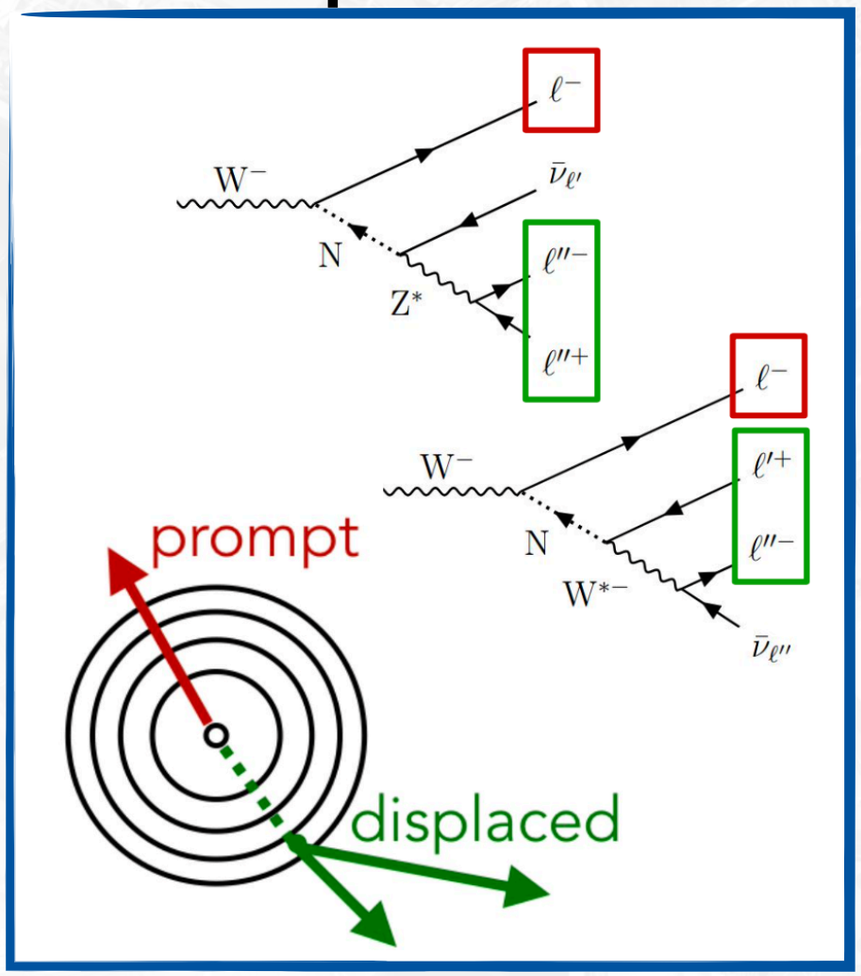
# Non conventional physics

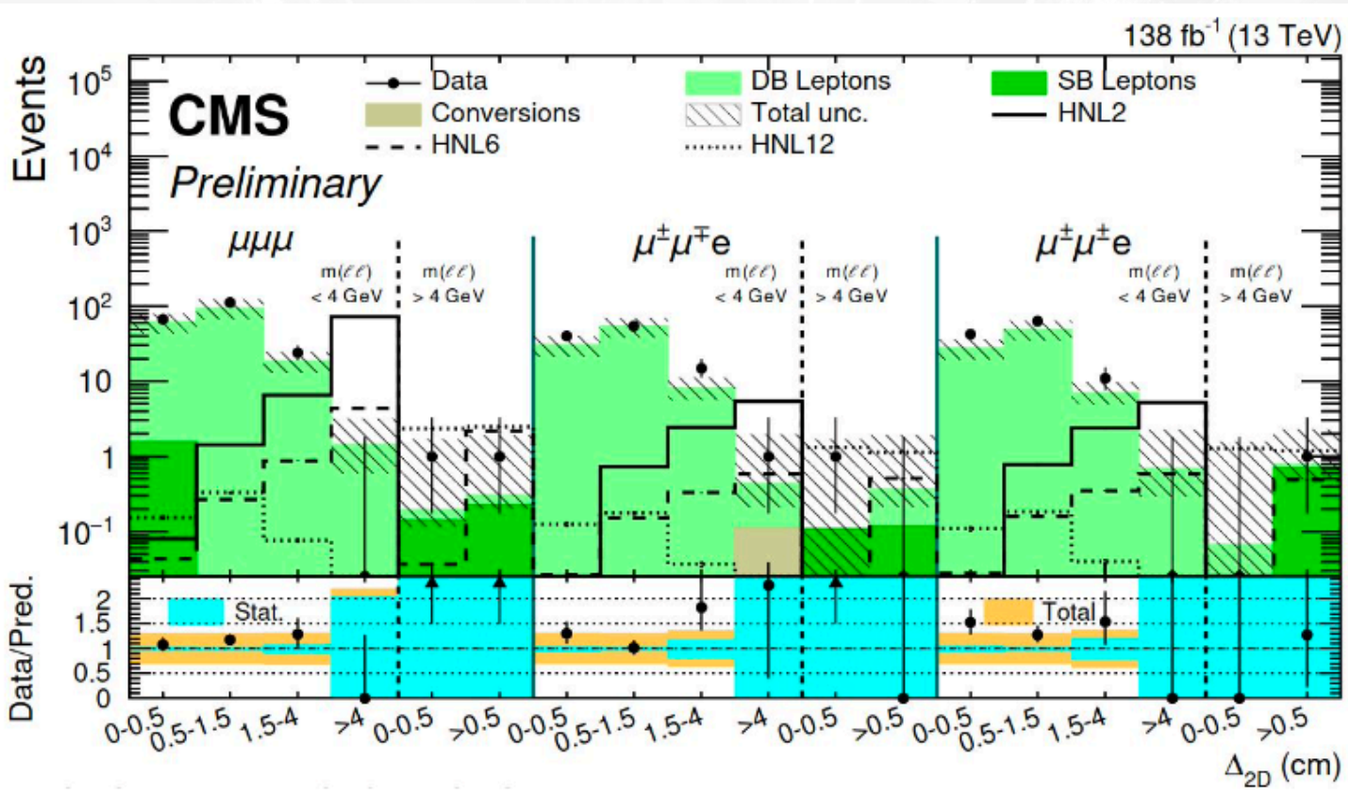


# Long lived Heavy Neutral Leptons

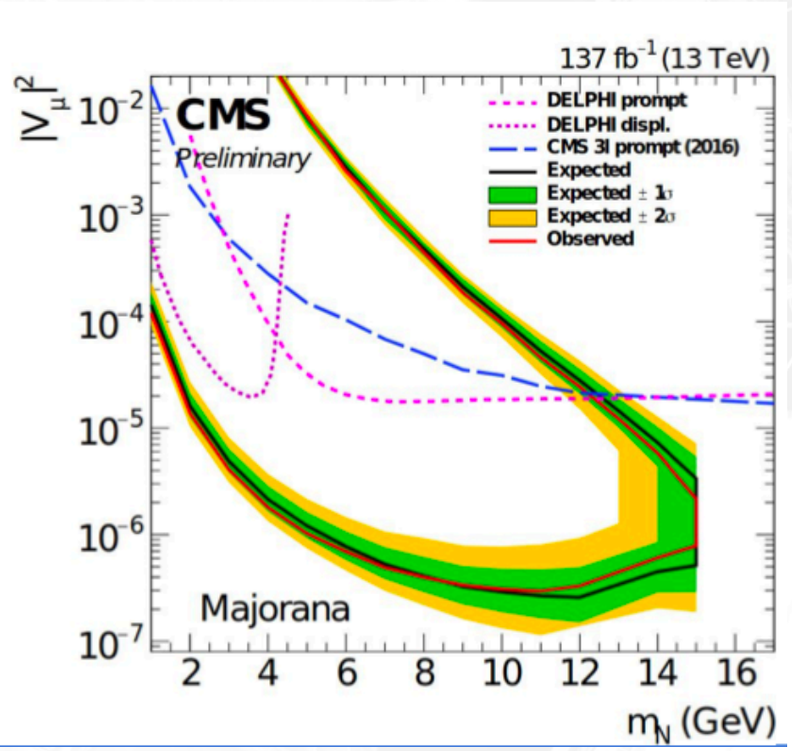
- HNL mix with SM neutrinos
- Small masses + small mixing → **long-lived HNL**

- Trigger on prompt **l** to enable sensitivity to low-momentum displaced **l**



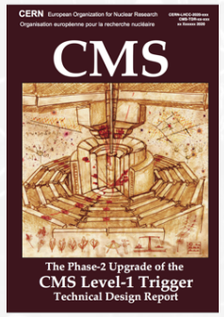

Constrain HNL neutrino mixing parameter values as a function of HNL mass




[CMS-PAS-EXO-20-009]

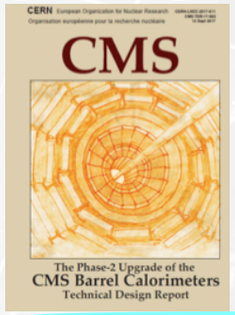
# *Phase 2 Activities*

# CMS Upgrade overview



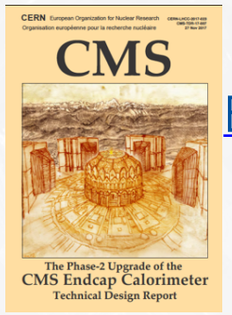

## L1-Trigger

- Tracks in L1-Trigger at 40 MHz
- PFlow selection 750 kHz L1



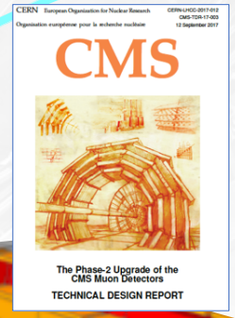

## Barrel Calorimeters

- ECAL readout at 40 MHz w/ precise timing at 30 GeV
- ECAL/HCAL new back-end boards




## Endcap Calorimeter

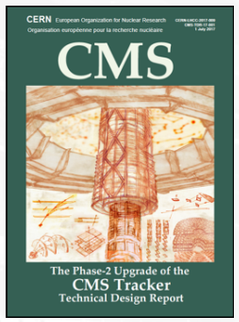
- 3D showers + precise timing
- Si, Scint+SiPM in Pb/W-SS




## Muon systems

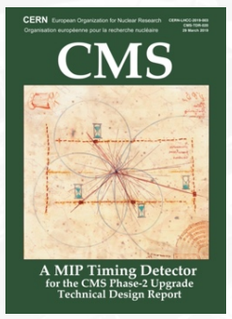
- DT/CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended to $\eta \simeq 3$






## Tracker

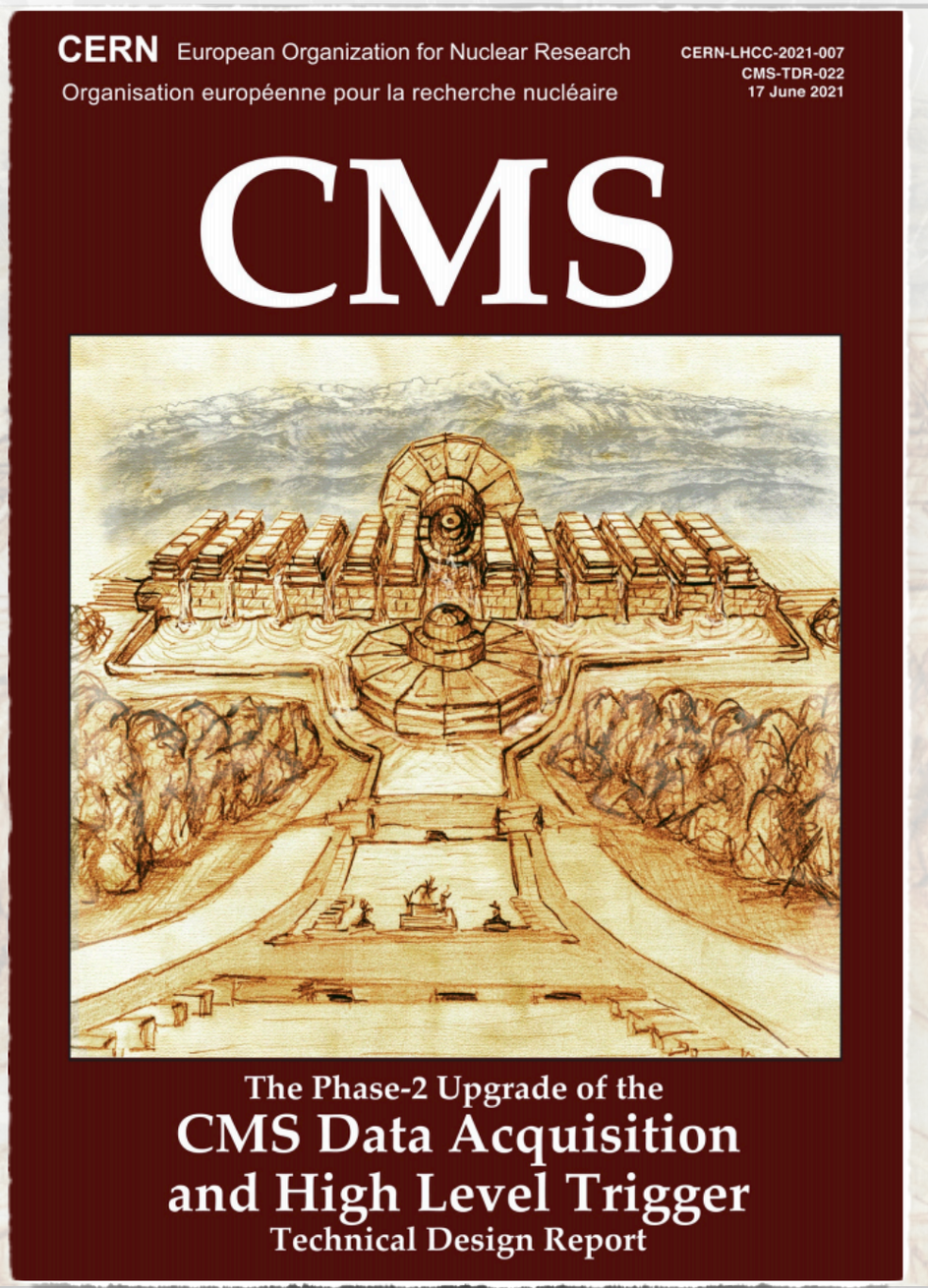
- Si-Strip/Pixels increased granularity
- Tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$




## MIP Timing Detector

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

# Latest Upgrade TDRs



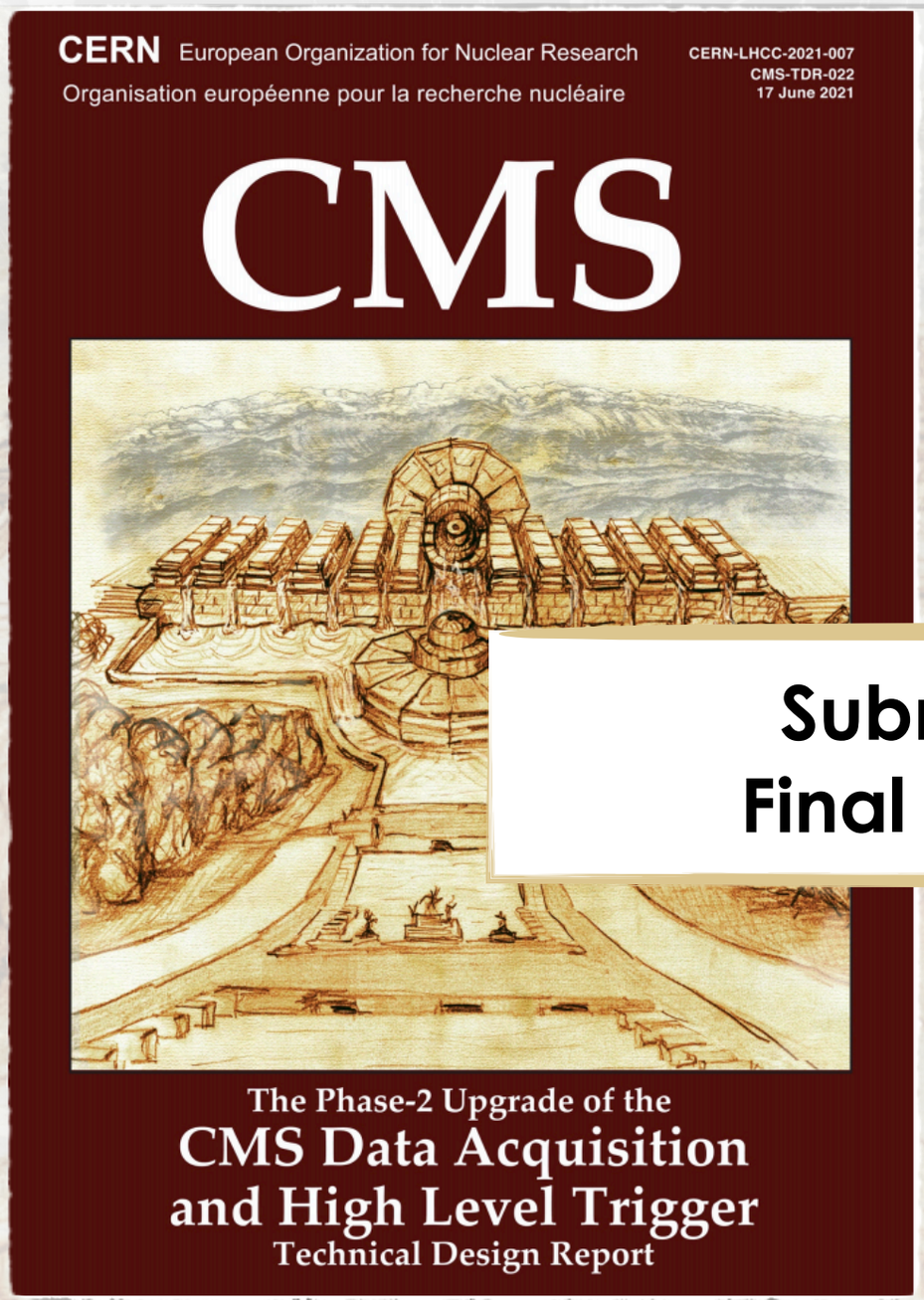

[HLT/DAQ]

- HLT output 7.5 kHz


[Beam Radiation Instr. and Luminosity]

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

# Latest Upgrade TDRs





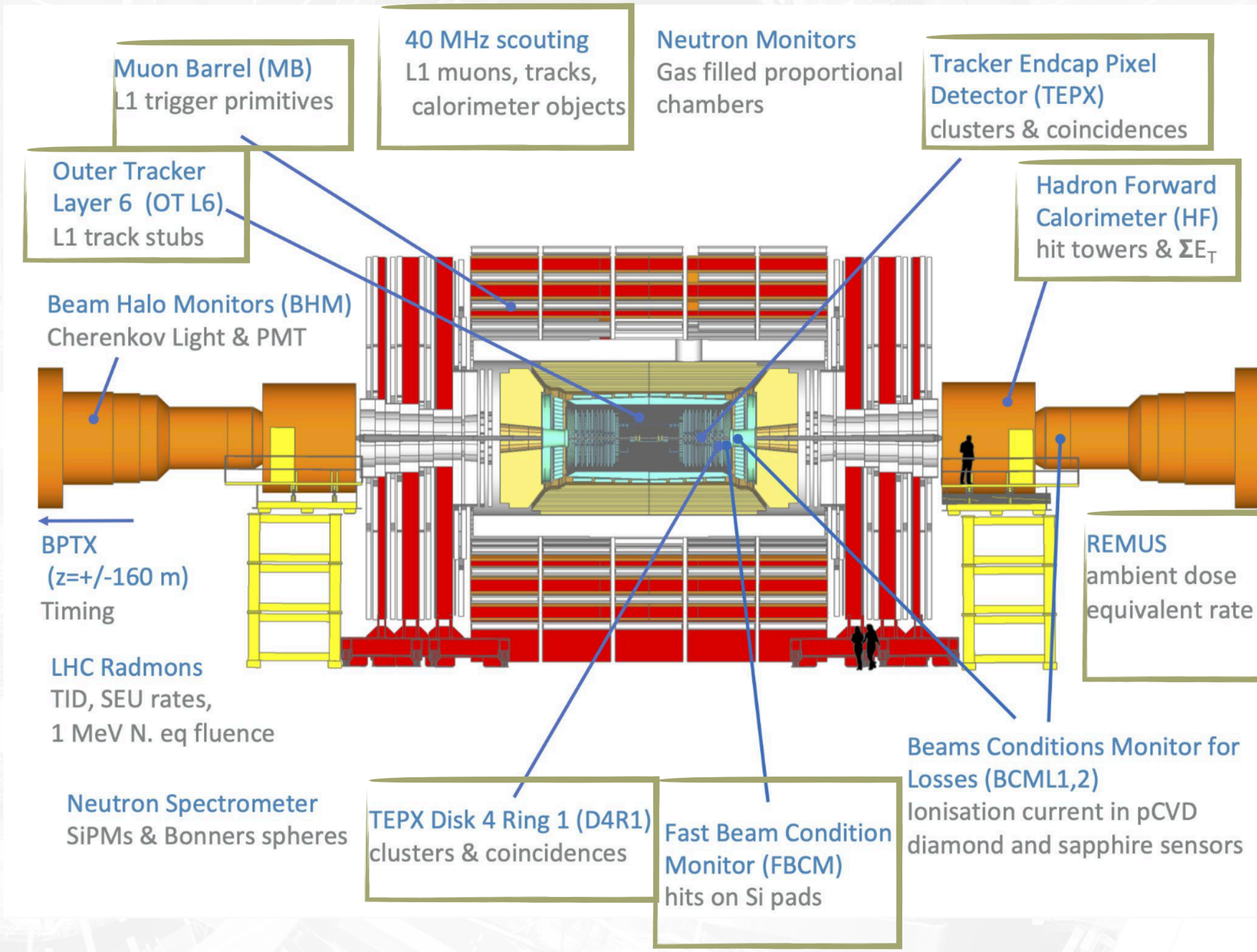
**Submitted mid-end June**
**Final Review end of August**

HLT/DAQ
- HLT output 7.5 kHz

Beam Radiation Instr. and Luminosity
- Bunch-by-bunch luminosity measurement: 1% offline, 2% online

# Phase-2 BRIL Upgrade

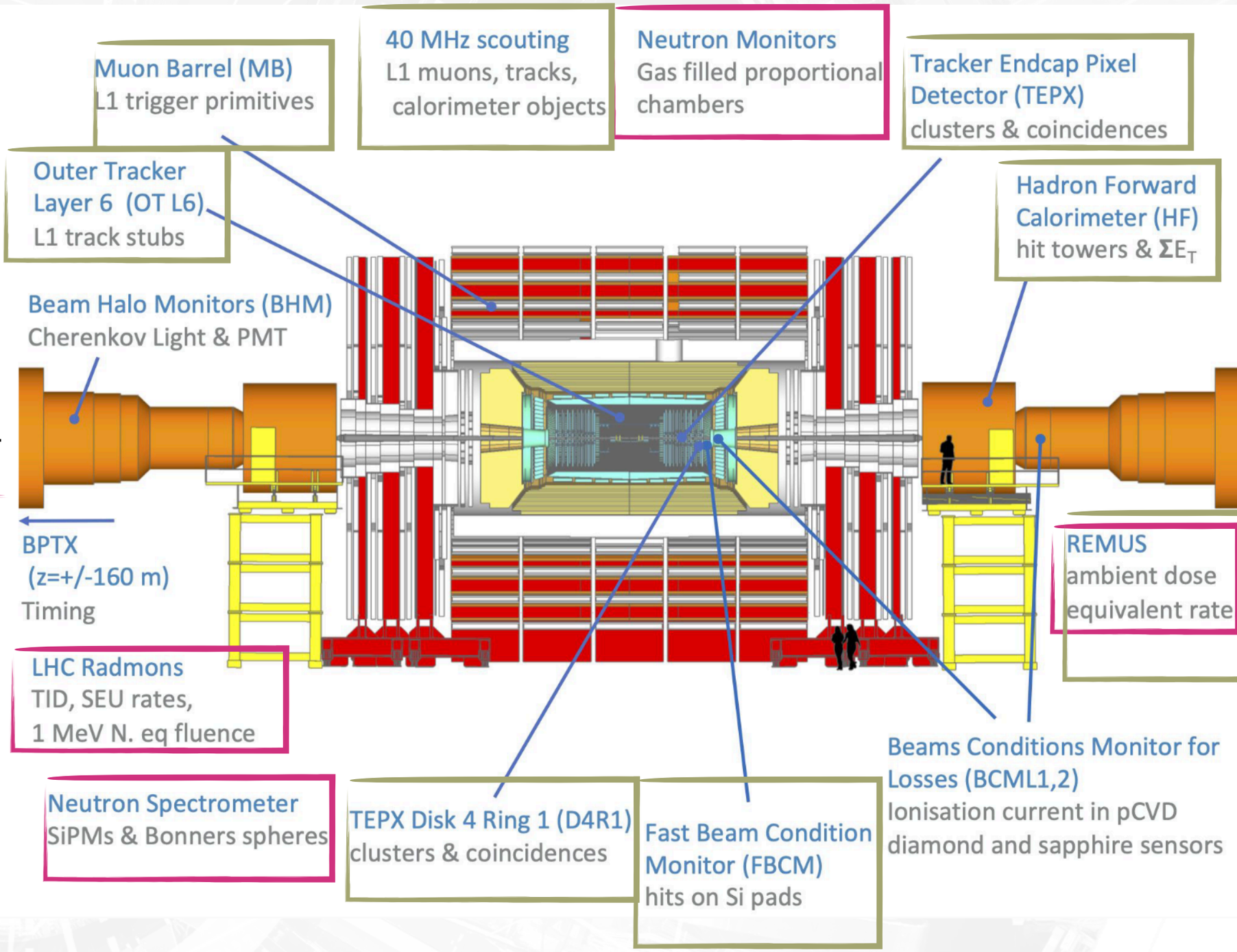
- Bunch by bunch luminosity
  - <1% offline
  - <2% real-time



# Phase-2 BRIL Upgrade

- Bunch by bunch luminosity
  - <1% offline
  - <2% real-time

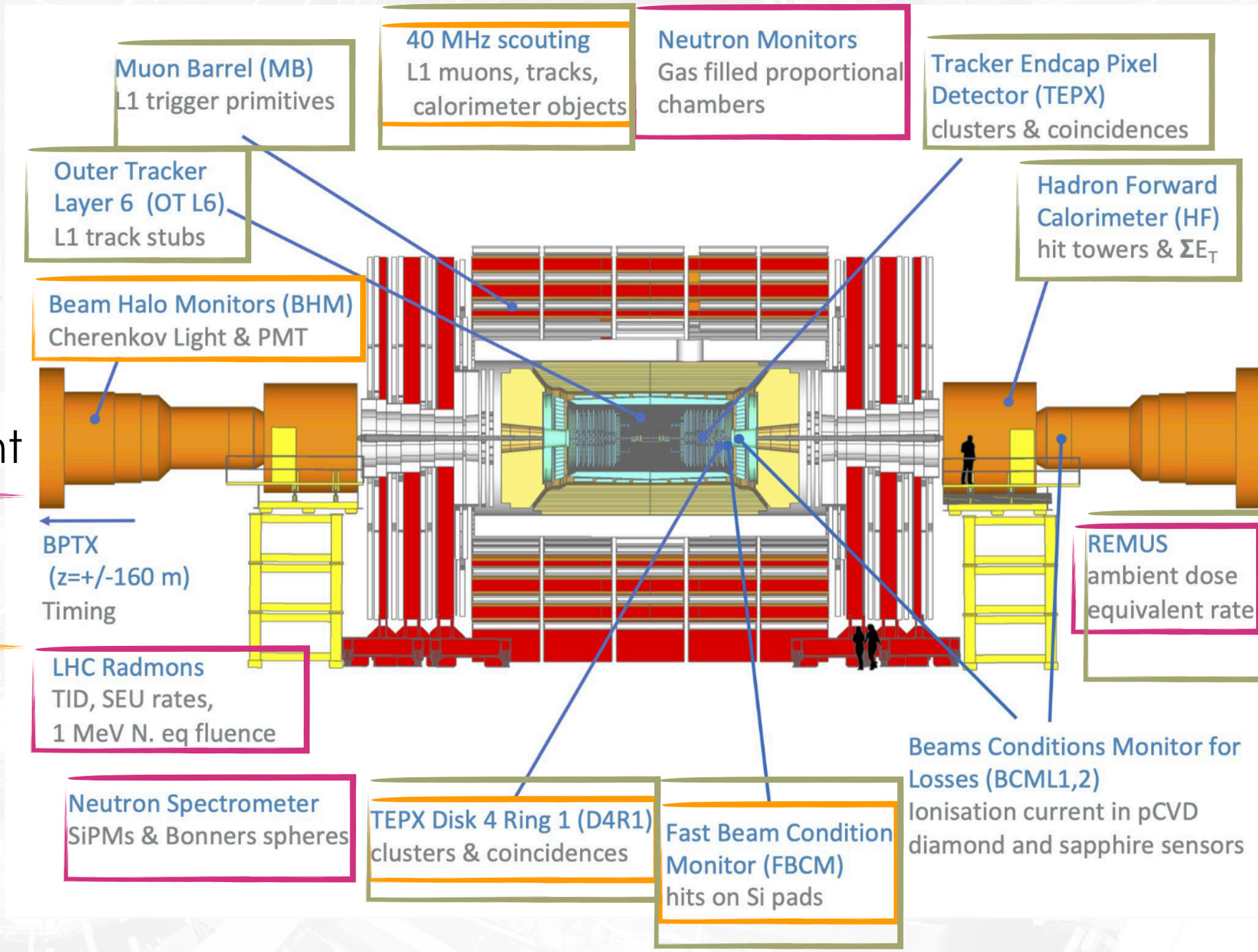
- Online Monitoring of:
  - radiation environment



# Phase-2 BRIL Upgrade

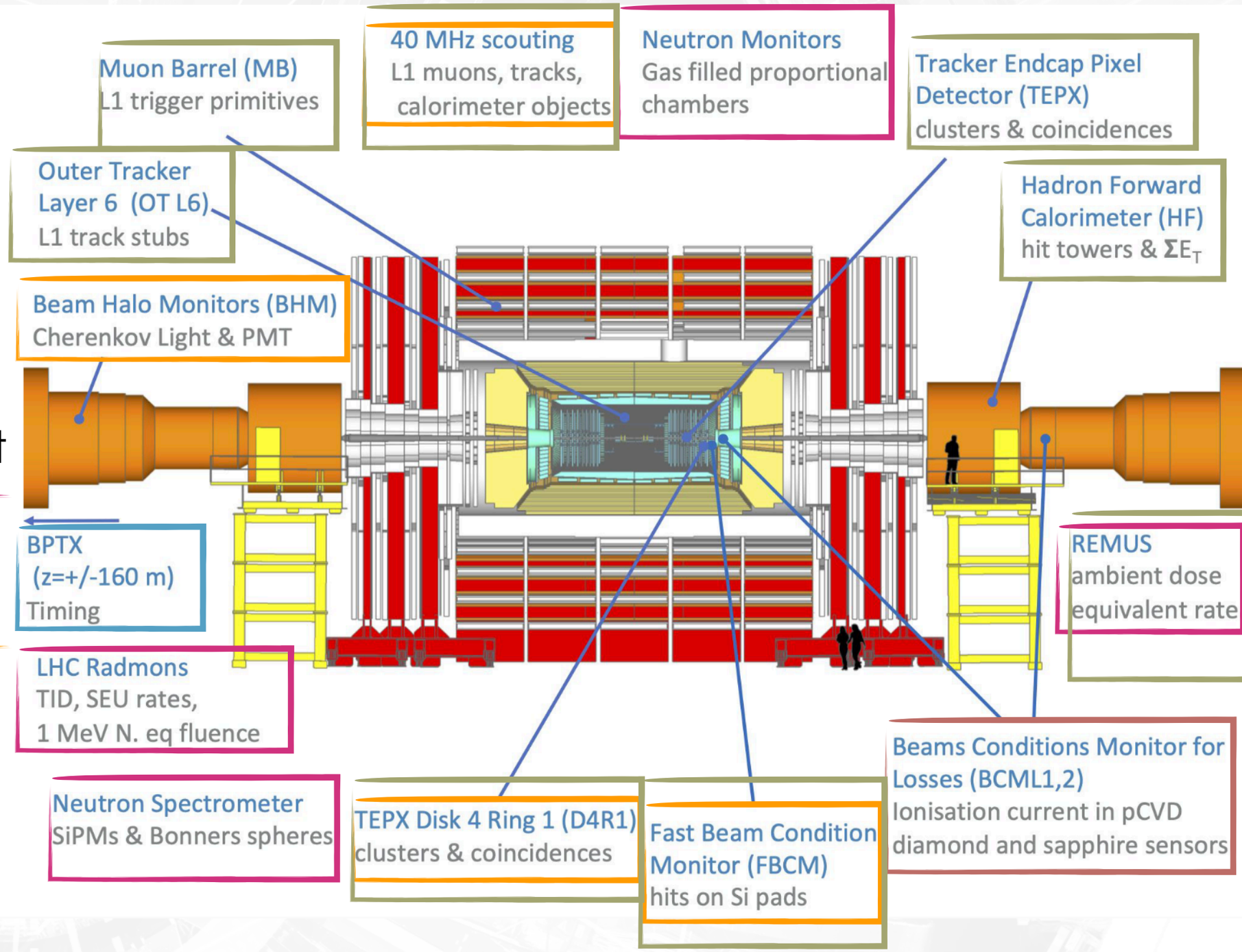
- Bunch by bunch luminosity
  - <1% offline
  - <2% real-time

- Online Monitoring of:
  - radiation environment
  - beam induced background

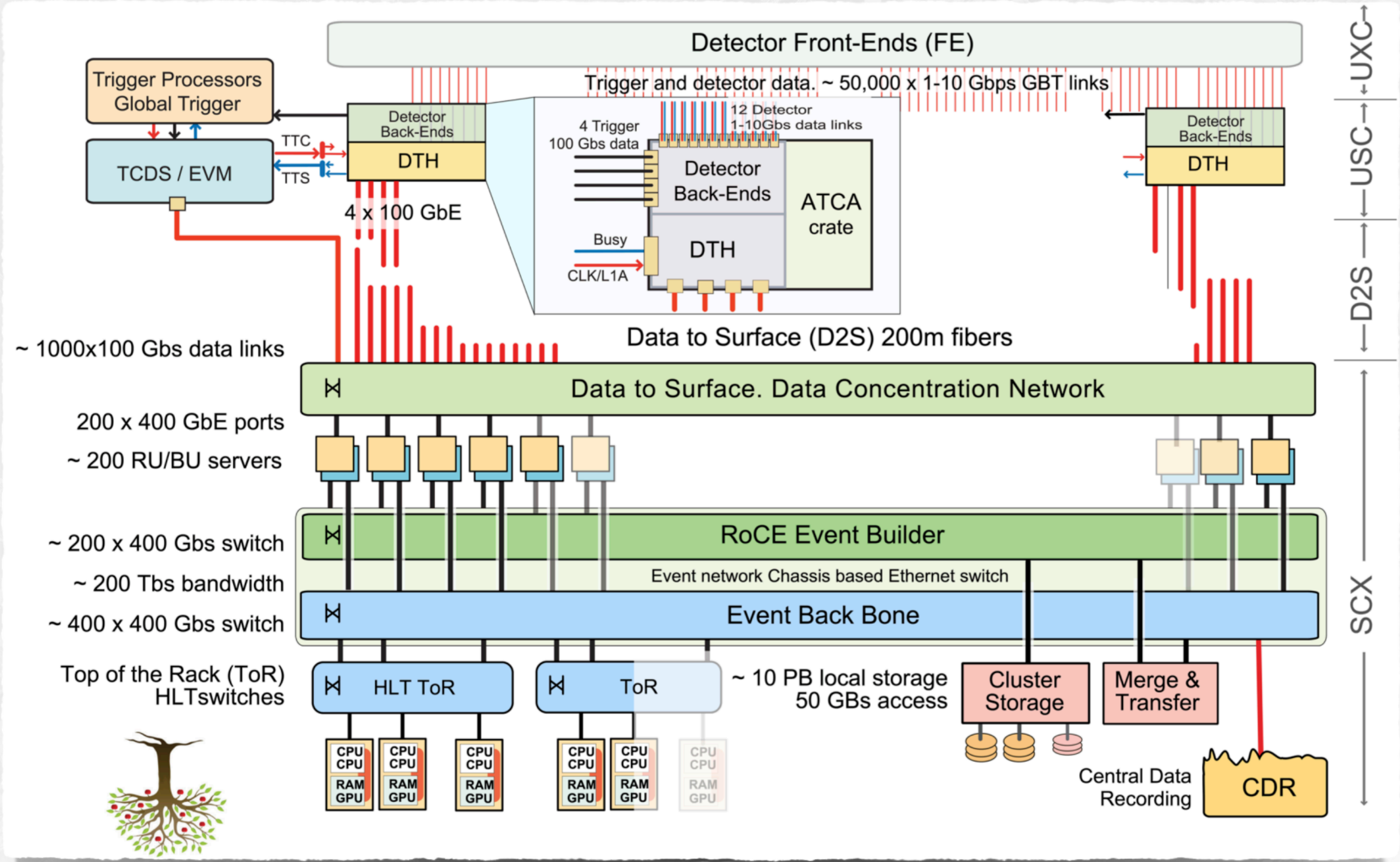


# Phase-2 BRIL Upgrade

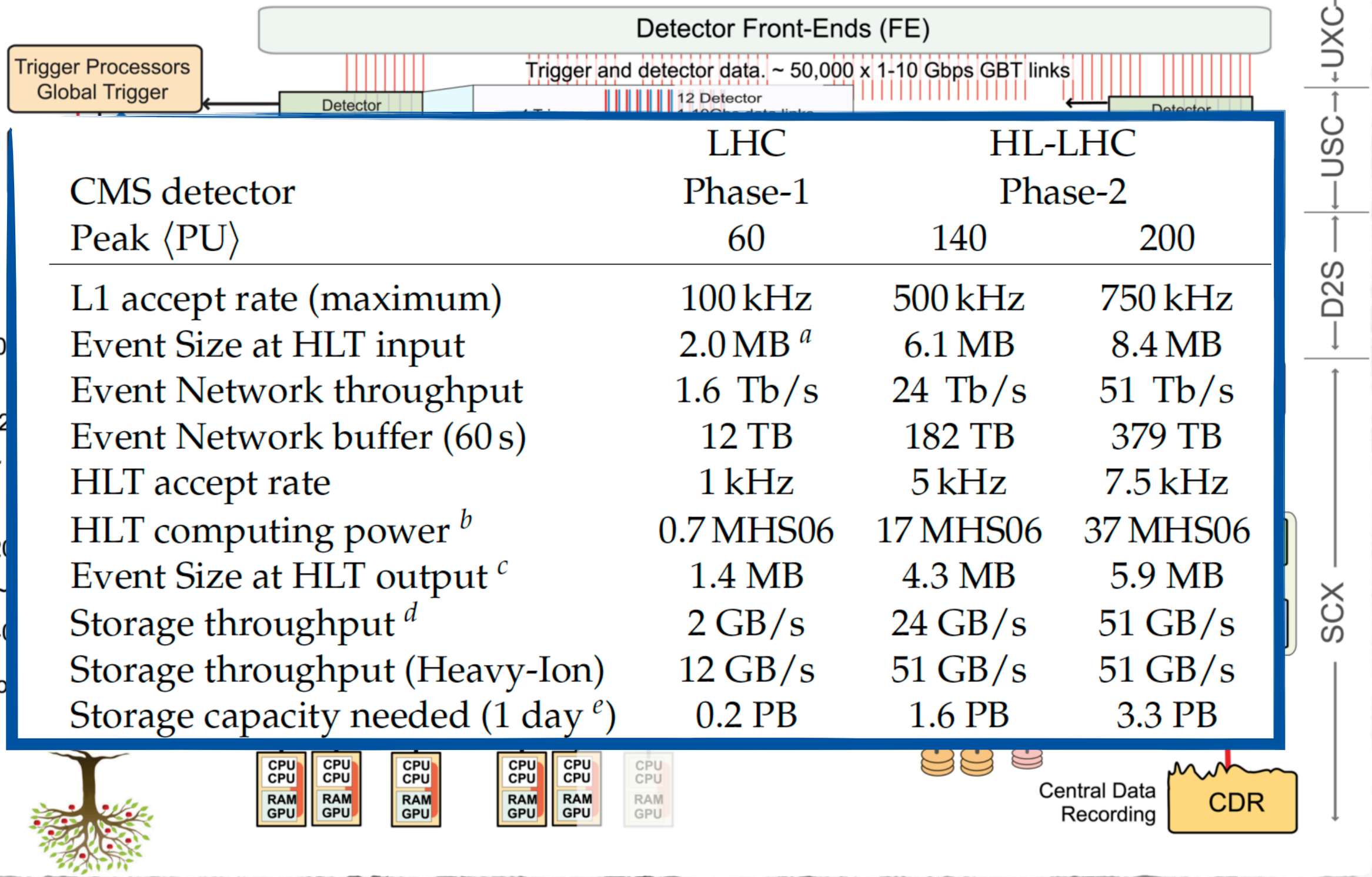
- Bunch by bunch luminosity
  - <1% offline
  - <2% real-time
- Online Monitoring of:
  - radiation environment
  - beam induced background
- Beam abort trigger
- Timing



# Phase-2 DAQ baseline



# Phase-2 DAQ Parameters




| CMS detector | LHC Phase-1 | HL-LHC Phase-2 | |
|---|---|---|---|
| Peak ⟨PU⟩ | 60 | 140 | 200 |
| L1 accept rate (maximum) | 100 kHz | 500 kHz | 750 kHz |
| Event Size at HLT input | 2.0 MB [a] | 6.1 MB | 8.4 MB |
| Event Network throughput | 1.6 Tb/s | 24 Tb/s | 51 Tb/s |
| Event Network buffer (60 s) | 12 TB | 182 TB | 379 TB |
| HLT accept rate | 1 kHz | 5 kHz | 7.5 kHz |
| HLT computing power [b] | 0.7 MHS06 | 17 MHS06 | 37 MHS06 |
| Event Size at HLT output [c] | 1.4 MB | 4.3 MB | 5.9 MB |
| Storage throughput [d] | 2 GB/s | 24 GB/s | 51 GB/s |
| Storage throughput (Heavy-Ion) | 12 GB/s | 51 GB/s | 51 GB/s |
| Storage capacity needed (1 day [e]) | 0.2 PB | 1.6 PB | 3.3 PB |

# Phase-2 HLT Realistic Menu

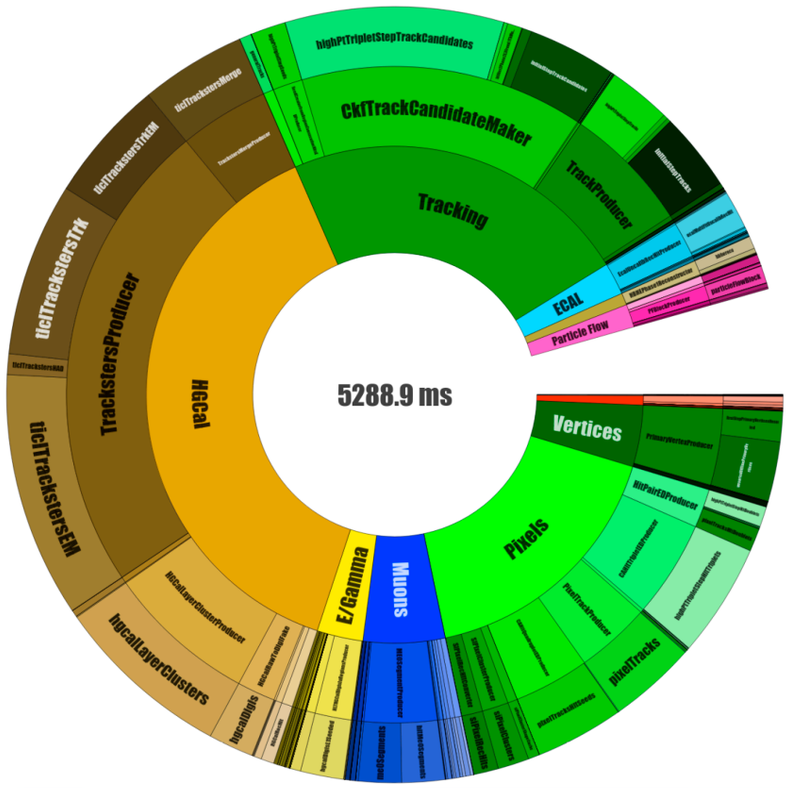
- Implemented in CMSSW
- Operation with **very similar thresholds as in Phase-1**

| Trigger type | Phase-1 | | Phase-2 | | | |
|---|---|---|---|---|---|---|
| | Threshold [GeV] | % rate | L1 seed | Threshold [GeV] | Rate at $\langle PU \rangle = 140$ [Hz] | Rate at $\langle PU \rangle = 200$ [Hz] |
| Single $\mu$ | 50 | 3% | `TkMu_22` | 50 | $155 \pm 6$ | $213 \pm 8$ |
| Single $\mu$ (isol.) | 24 | 14% | `TkMu_22` | 24 | $943 \pm 32$ | $1\,111 \pm 29$ |
| Double $\mu$ | 37, 27 | 1% | `TkMu_15_7` | 37, 27 | $27 \pm 1$ | $40 \pm 1$ |
| Double $\mu$ (isol.) | 17, 8 | 2% | `TkMu_15_7` | 17, 8 | $113 \pm 11$ | $143 \pm 13$ |
| Triple $\mu$ | 5, 3, 3 | 0.5% | `TkMu_5_3_3` | 10, 5, 5 | $39 \pm 8$ | $48 \pm 8$ |
| Single e (isol.) | 28 | 13% | `StaEG_51 OR TkEle_36 OR TkIsoEle_28` | 32 (WP1) 26 (WP2) | $609 \pm 27$ $664 \pm 47$ | $1\,005 \pm 33$ $1\,012 \pm 33$ |
| Double e | 25, 25 | 1% | `TkEle_25_12 OR StaEG_37_24` | 25, 25 | $46 \pm 4$ | $82 \pm 6$ |
| Double e (isol.) | 23, 12 | 1% | `TkEle_25_12 OR StaEG_37_24 OR TkIsoEle_22_StaEG_12` | 23, 12 | $52 \pm 5$ | $104 \pm 9$ |
| Single $\gamma$ | 200 | 1% | `StaEG_51` | 187 | $32 \pm 1$ | $56 \pm 6$ |
| Single $\gamma$ (isol.) | 110, EB only | 1% | `StaEG_51 OR TkIsoPho_36` | 108, EB only | $35 \pm 9$ | $52 \pm 7$ |
| Double $\gamma$ | 30, 18 | 2% | `StaEG_37_24 OR TkIsoPho_22_12` | 30, 23 | $123 \pm 12$ | $179 \pm 14$ |
| Double $\tau$ | 35, 35 | 3% | `HPSPFTau_21_21` | 22, 22 | $106 \pm 18^{\dagger}$ | $159 \pm 27$ |
| Single jet | 500 | 1% | `PuppiJet_230` | 520 | $53 \pm 1$ | $76 \pm 1$ |
| $H_T$ | 1050 | 1% | `PuppiHT_450` | 1 070 | $53 \pm 1$ | $74 \pm 1$ |
| Missing $p_T$ | 120 | 3% | `PuppiMET_220` | 140 | $79 \pm 7$ | $228 \pm 20$ |
| Multijets with b-tagging | $H_T = 330$ jets = 75, 60, 45, 40 | 1% | `PuppiJet_70_55_40_40_PuppiHT_328` | $H_T = 330$ jets = 75, 60, 45, 40 | $32 \pm 4$ | $48 \pm 5$ |
| **Total rate** | | **49%** | | | **2 525 ± 57** | **3 621 ± 62** |

# Phase-2 HLT Realistic Menu

- Implemented in CMSSW
- Operation with **very similar thresholds as in Phase-1**

| Trigger type | Phase-1 | | Phase-2 | | | |
|---|---|---|---|---|---|---|
| | Threshold [GeV] | % rate | L1 seed | Threshold [GeV] | Rate at $\langle PU \rangle = 140$ [Hz] | Rate at $\langle PU \rangle = 200$ [Hz] |
| Single $\mu$ | 50 | 3% | `TkMu_22` | 50 | $155 \pm 6$ | $213 \pm 8$ |
| Single $\mu$ (isol.) | 24 | 14% | `TkMu_22` | 24 | $943 \pm 32$ | $1\,111 \pm 29$ |
| Double $\mu$ | 37, 27 | 1% | `TkMu_15_7` | 37, 27 | $27 \pm 1$ | $40 \pm 1$ |
| Double $\mu$ (isol.) | 17, 8 | 2% | `TkMu_15_7` | 17, 8 | $113 \pm 11$ | $143 \pm 13$ |
| Triple $\mu$ | 5, 3, 3 | 0.5% | `TkMu_5_3_3` | 10, 5, 5 | $39 \pm 8$ | $48 \pm 8$ |
| Single e (isol.) | 28 | 13% | `StaEG_51 OR TkEle_36 OR TkIsoEle_28` | 32 (WP1)<br>26 (WP2) | $609 \pm 27$<br>$664 \pm 47$ | $1\,005 \pm 33$<br>$1\,012 \pm 33$ |
| Double e | 25, 25 | 1% | `TkEle_25_12 OR StaEG_37_24` | 25, 25 | $46 \pm 4$ | $82 \pm 6$ |
| Double e (isol.) | 23, 12 | 1% | `TkEle_25_12 OR StaEG_37_24 OR TkIsoEle_22_StaEG_12` | 23, 12 | $52 \pm 5$ | $104 \pm 9$ |
| Single $\gamma$ | 200 | 1% | `StaEG_51` | 187 | $32 \pm 1$ | $56 \pm 6$ |
| Single $\gamma$ (isol.) | 110, EB only | 1% | `StaEG_51 OR TkIsoPho_36` | 108, EB only | $35 \pm 9$ | $52 \pm 7$ |
| Double $\gamma$ | 30, 18 | 2% | `StaEG_37_24 OR` | 30, 23 | $123 \pm 12$ | $179 \pm 14$ |




- **Workable systems in Run4 and Run5** within interim TDR budget, **using GPUs and a 1.6-4x code improvement** in the next 10 years

| Scenario | Year | | Cost (MCHF) | CHF/HS06 W/ GPU | Capacity (MHS06) | Est. need (MHS06) | Missing factor |
|---|---|---|---|---|---|---|---|
| Run-4 | 2028 | 20%/y | 11.4 | 0.70 | 16.3 | 26.1 | 1.6× |
| | | 15%/y | 11.4 | 0.99 | 11.6 | 26.1 | 2.3× |
| Run-5 | 2032 | 20%/y | 4.6 | 0.22 | 37.1 (16.3 + 20.8) | 93.6 | 2.5× |
| | | 15%/y | 4.6 | 0.37 | 24.1 (11.6 + 12.5) | 93.6 | 3.9× |

# Conclusions

- **Long Shutdown 2** on schedule:
  - Succesfull **pixel** installation
  - **Magnet** cooling down smoothly

- **Successful summer data taking** at PT5:
  - Pixel **alignment**
  - **GPU** integration @ HLT

- **45 New physics results** (LHCP, EPS, SUSY)
  - From Electroweak measurements to BSM searches

- Two new **upgrade TDRs**:
  - **BRIL TDR** : possibility of < 1% uncertainty on integrated luminosity
  - **DAQ/HLT TDR** : preserves same trigger thresholds throughout running

***We are excited to re-start data taking beginning of 2022!***