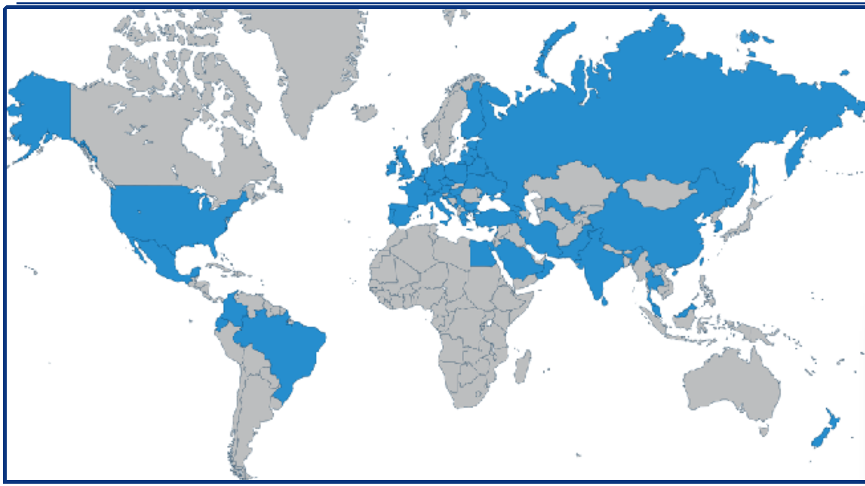
CMS Upgrades for the HL-LHC

P. McBride for the CMS SP team
USCMS HL-LHC Upgrade Director's Review
Fermilab
19.03.2019

about me

- CMS Deputy Spokesperson (DSP)
  - with Roberto Carlin SP and Luca Malgeri DSP
- Distinguished Scientist at Fermilab
- Previously:
  - PPD Division Head
  - USCMS Operations Program Manager
  - Fermilab CMS Center Head
  - Deputy Head of the Computing Division
  - Deputy CMS Computing Coordinator

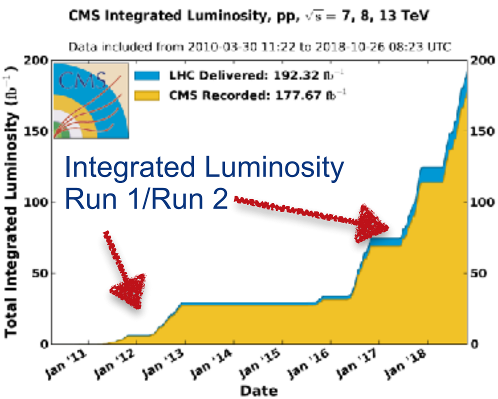
The CMS Collaboration



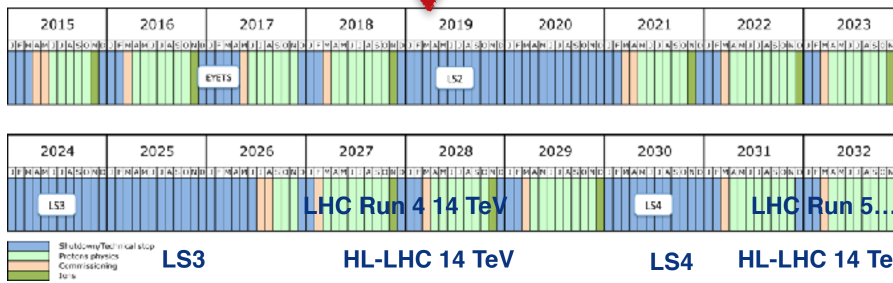
CMS Collaboration	Statistics
Countries	46
Member Institutes	201
CMS Authors	2169
CMS Members	5428
Graduate Students	1041

- The CMS Collaboration remains a vibrant, diverse community after 26 years and we look forward to the opportunities of the HL-LHC era.
- In addition, CMS has 19 Associated Institutes and 7 Cooperating Institutes
- CMS recently added 7 new institutes.

CMS at the LHC

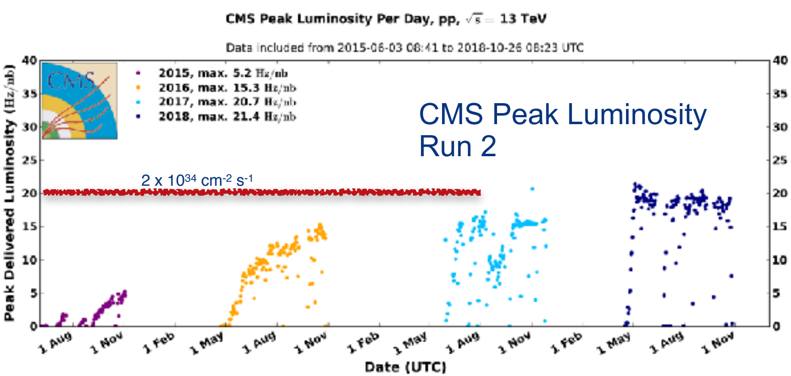


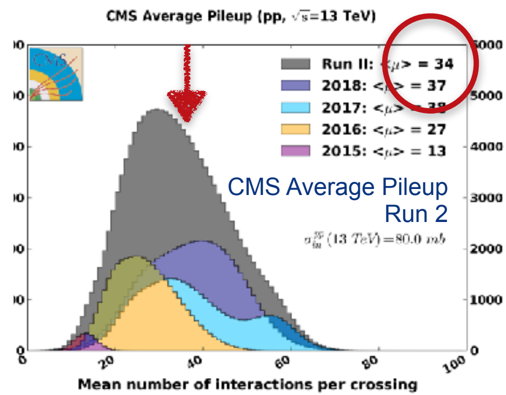
LHC Run 2 160 fb^{-1} 13 TeV LS2 LHC Run 3 ~200 fb^{-1} 14 TeV



LS3 HL-LHC 14 TeV LS4 HL-LHC 14 TeV

HL-LHC goal 3000 fb^{-1}





Goal of HL-LHC was fixed in 2010

From FP7 HiLumi LHC Design Study application

The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

A peak luminosity of L_{peak} = **5×10^{34} cm^{-2}s^{-1} with levelling**, allowing:

An integrated luminosity of **250 fb^{-1} per year**, enabling the goal of **L_{int} = 3000 fb^{-1}** twelve years after the upgrade.

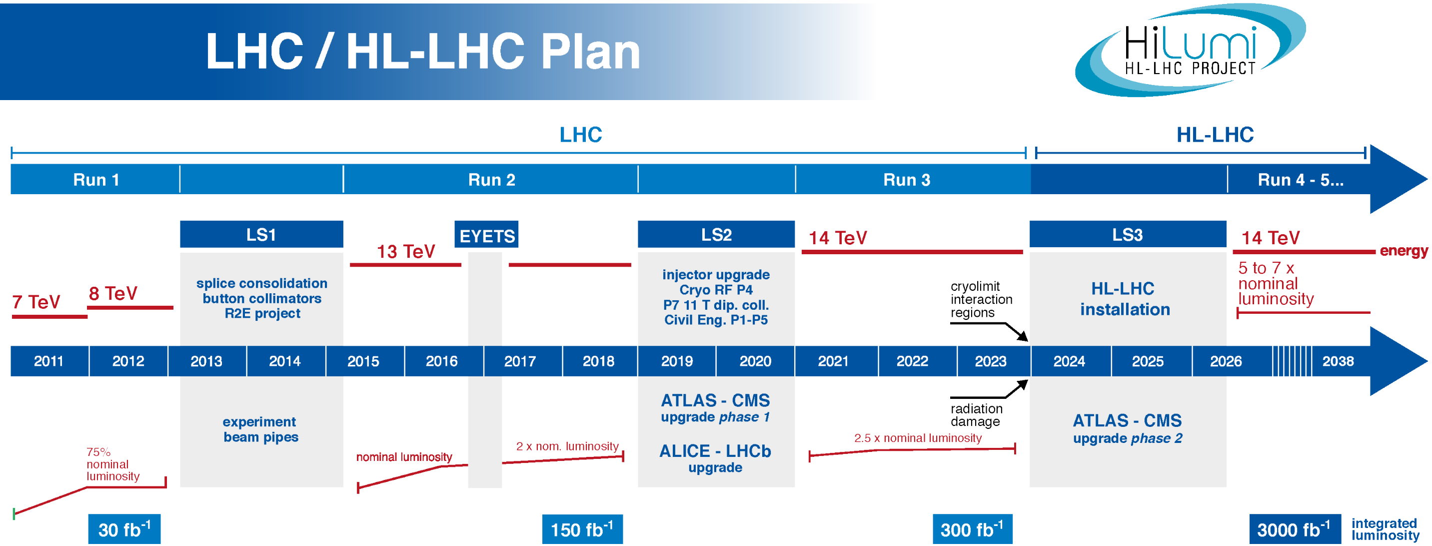
This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

Ultimate performance established 2015-2016: with same hardware and same beam parameters: use of **engineering margins:**

$L_{peak\ ult}$ ≅ 7.5 10^{34} cm^{-2}s^{-1} and **Ultimate Integrated $L_{int\ ult}$ ~ 4000 fb^{-1}**

LHC should not be the limit, would Physics require more…

LHC/HL-LHC plan



At CERN, the detector upgrades for the HL-LHC are called the Phase-2 upgrades. The Phase-1 CMS upgrades are nearly complete. The installation of the HCAL barrel upgrade is ongoing now.

Physics at the HL-LHC

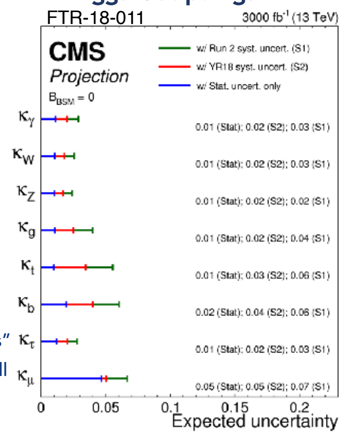
- HL-LHC will enable unprecedented precision in measurements of standard model (SM) properties, and expand the discovery reach

P5 1.”**Use the Higgs boson as a new tool for discovery**”
- 2-5% on Higgs Couplings (except for Zγ)
- First evidence of di-Higgs production (Higgs self-couplings) needs full HL-LHC stats (3ab^{-1})

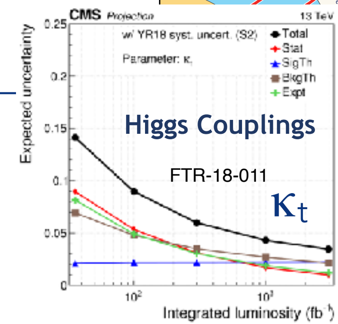
P5 III.”**Identify the new physics of dark matter**”
- Access to small cross section SUSY processes
- e.g. Stau discovery with 5σ (not possible with 300 fb^{-1})

P5 V.”**Explore the unknown: new particles, interactions and physics principles**”
- Study of rare SM processes and discovery of new heavy particles with small cross sections (Dark Matter, Vector-like-quark, Long-Lived particles…)
- MTD extends the reach for new particle searches

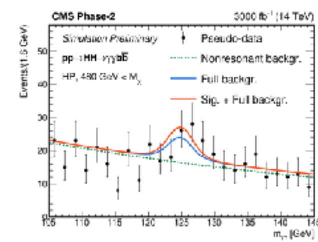
Higgs Couplings



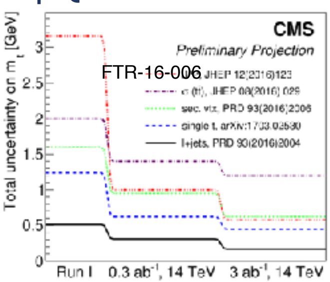
Higgs Couplings



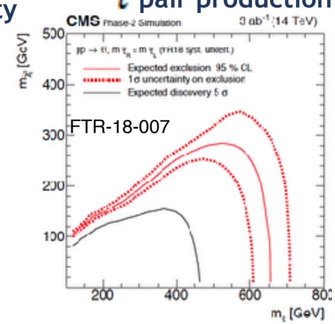
Di-Higgs production



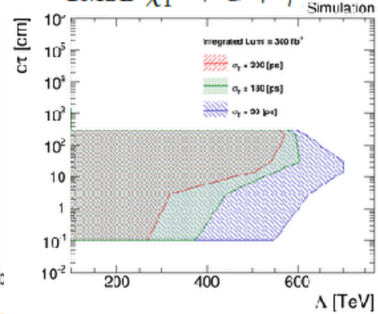
Top Quark mass uncertainty



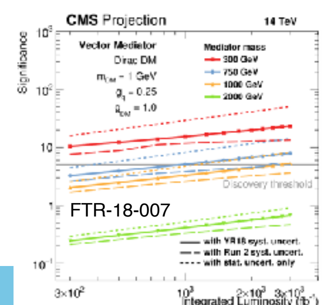
$\tilde{\tau}$ pair production



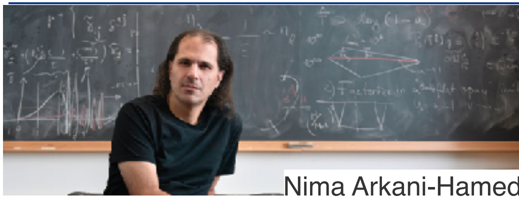
GMSB $\tilde{\chi}_1^0 \to \tilde{G} + \gamma$



Dark Matter (mono-Z)



The HL-LHC (and beyond)



Nima Arkani-Hamed

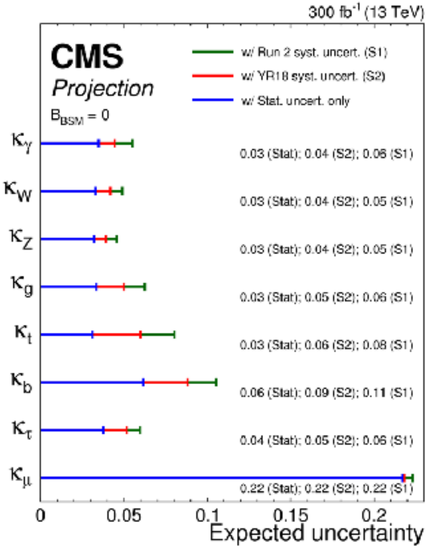
"The discovery of the **Higgs particle** – especially with nothing else accompanying it so far – is unlike anything we have seen in any state of nature, and is profoundly "new physics" in this sense. …theoretical attempts to compute the vacuum energy and the scale of the Higgs mass pose gigantic, and perhaps interrelated, theoretical challenges. While we continue to scratch our heads as theorists, the most important **path forward for experimentalists is completely clear**: measure the hell out of these crazy phenomena!"

"It is the first example we've seen of the simplest possible type of elementary particle. It has no spin, no charge, only mass, and this extreme simplicity makes it theoretically perplexing. …"

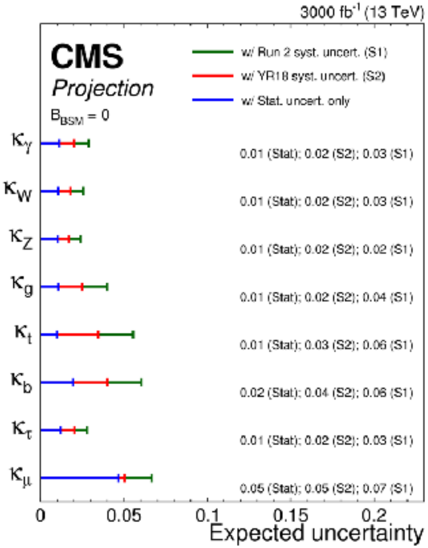
https://cerncourier.com/in-it-for-the-long-haul/

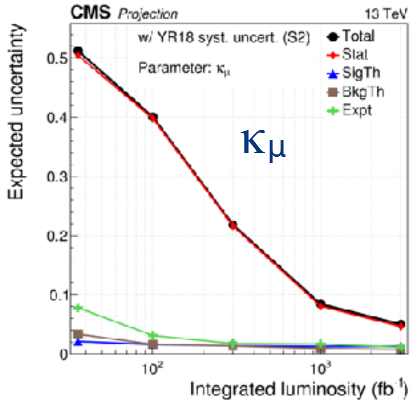
CERN HL-LHC Physics Studies

Higgs couplings after Run 3 (~2025)



Higgs couplings after HL-LHC (3ab^{-1})





Much more information in the HL/HE-LHC Yellow Report (YR)

for details see https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCWorkshop

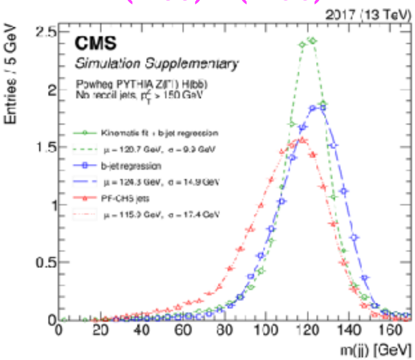
https://cms.cern/news/it-takes-village-future-studies-high-luminosity-lhc

Observation of H→bb

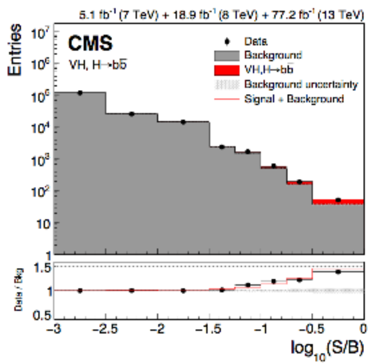
In 2018 CMS (and ATLAS) presented the observation of the Higgs boson coupling to b quarks. Together with the recent observations of the couplings to τ lepton and top quark, we have observed the coupling of the Higgs to 3rd generation fermions

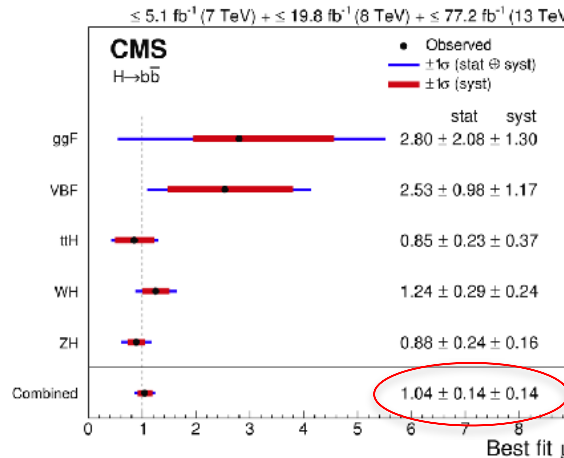
- Improved VH(bb) analysis included 2017 data
  - better b-jet identification, energy regression for b jets, use of deep neural networks and S/B discrimination
- combination VH(bb): 4.8σ observed; **all production modes: 5.6σ observed**

Z(→ℓℓ) H(→bb)



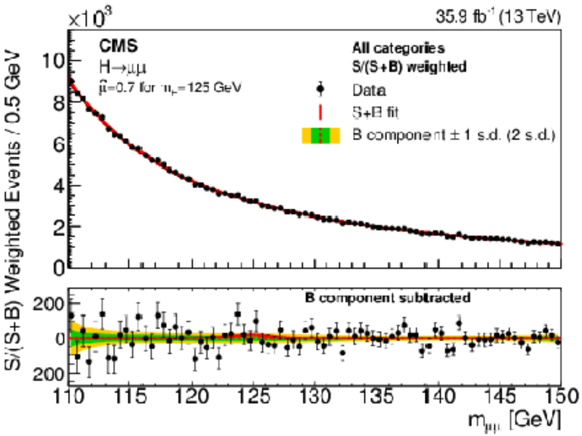
VH, H(→bb)

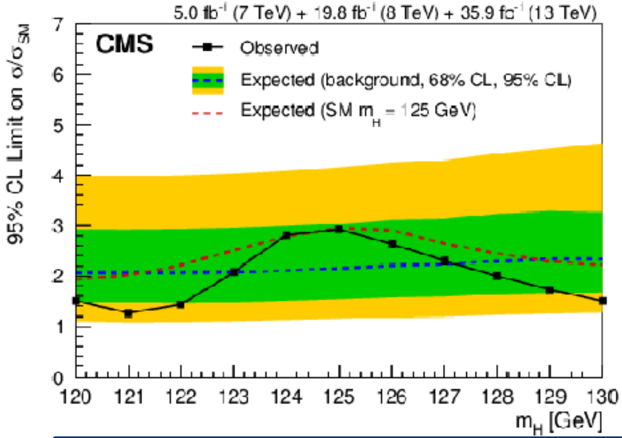




Higgs to two muons

arXiv:1807.06325 , submitted to PRL

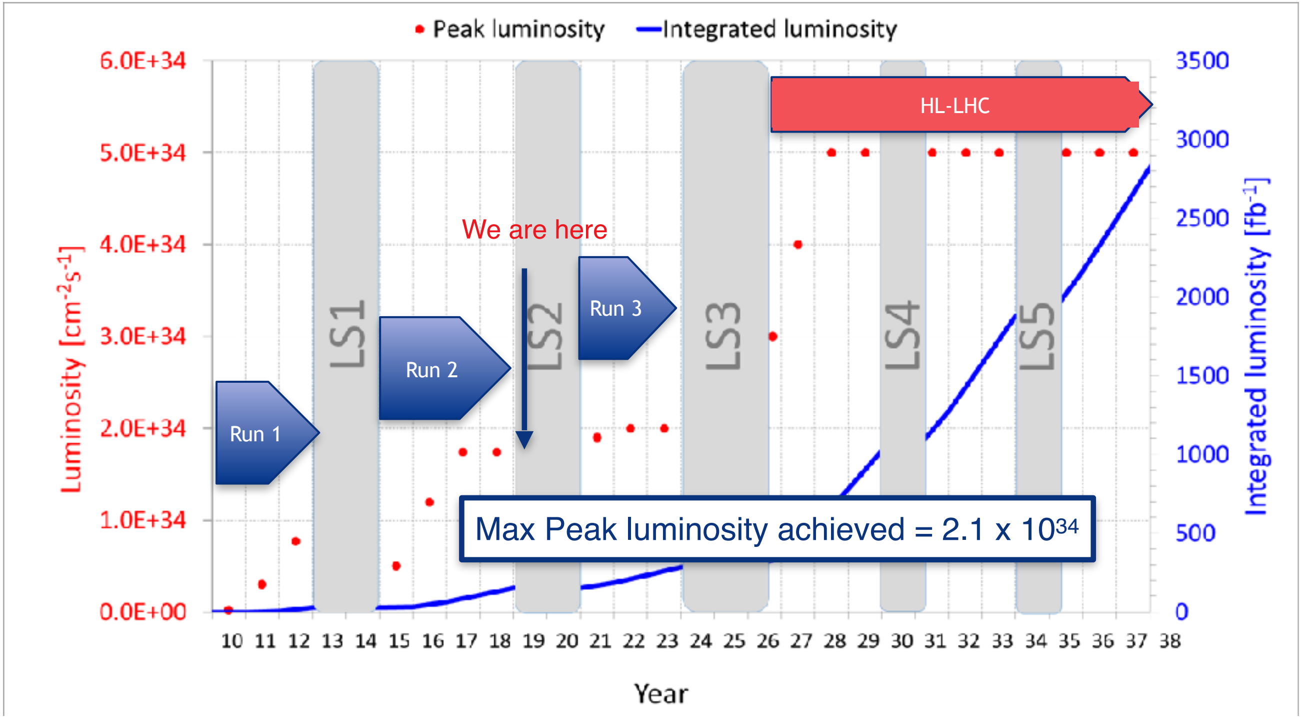




CMS is already tackling H →μμ thanks to excellent detector performance
Looking forward to an updated result with full Run 2 statistics

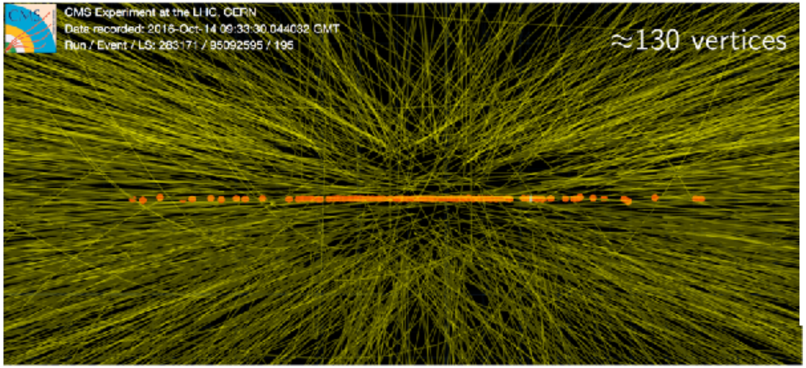
Upper limit on the SM Higgs branching fraction to muons of 6.4 x 10^{-4}. UL observed (expected) is 2.92 (2.16) times the SM value with Run 1 and early Run 2 data.

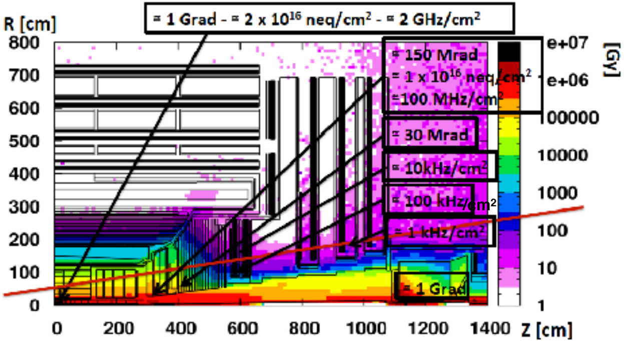
Nominal HL-LHC performance



Challenges of the HL-LHC

- HL-LHC and the CMS detector requirements:
  - Be able to trigger, read out and analyze data with high instantaneous luminosity and PU up to 140 (200)
  - Be able to manage a much higher instantaneous and integrated radiation dose
    - Up to 2×10^{16} 1MeV n_{equiv} and 1GRad in the innermost radius





CMS radiation dose map, neutron equivalent fluence, and particle rates for luminosities of 3000 fb $^{-1}$(integrated) and 5 x 10^{34} Hz/cm^2 (instantaneous).

CMS HL-LHC Upgrade

Technical proposal CERN-LHCC-2015-010 https://cds.cern.ch/record/2020886
Scope Document CERN-LHCC-2015-019 https://cds.cern.ch/record/2055167/files/LHCC-G-165.pdf

L1-Trigger/HLT/DAQ

https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193

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

Barrel Calorimeters

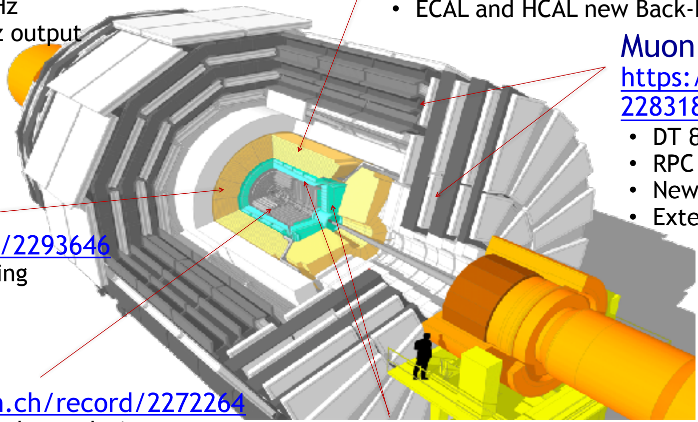
https://cds.cern.ch/record/2283187

- 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 link -board
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η ≃ 3



Calorimeter Endcap

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

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

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure

https://cds.cern.ch/record/2020886

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

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

MIP Timing Detector

https://cds.cern.ch/record/2296612

Precision timing with:

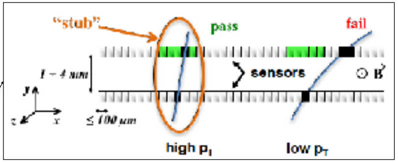
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

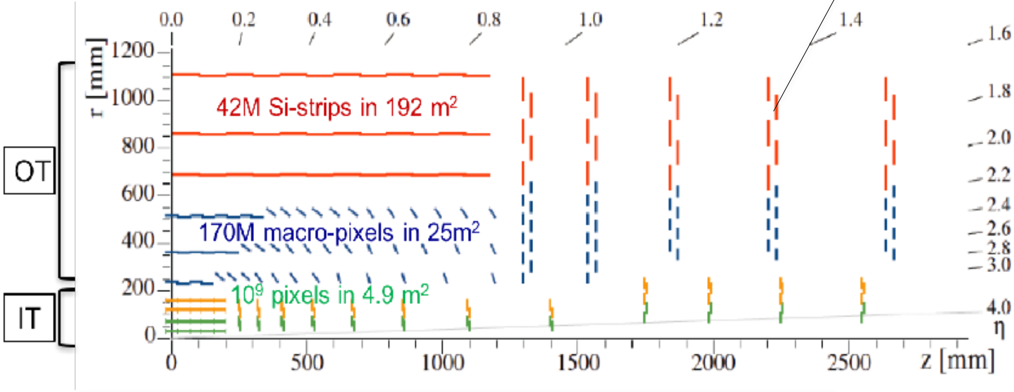
New paradigms (design/technology) for an HEP experiment to fully exploit HL-LHC luminosity

CMS Tracker Upgrade (OT/IT)

- Outer Tracker design driven by ability to provide tracks at 40 MHz to L1-trigger
- Tilted modules in OT 3 inner layers
- Inner Tracker (pixel) design to extend coverage to η ≃ 3.8

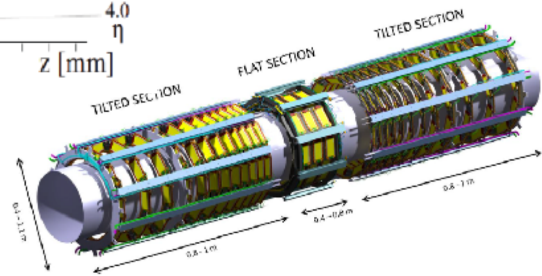
2-sensor modules concept for L1 track-trigger





OT Si-sensors ≃ 200µm thick - 90/100µm pitch - 2.5/5cm strips - 1.5 mm macro-pixels in inner layers

Enhanced radiation tolerance; OT longevity up to 4000 fb^{-1}
Improved two track separation in high energy jets
huge data rate capability



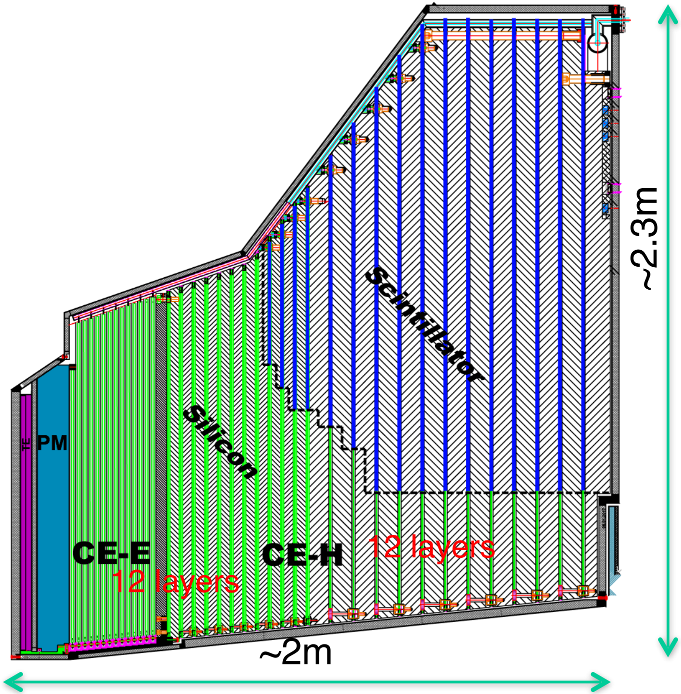
CMS High Granularity Calorimeter (HGCAL/CE)

Active Elements:

- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
- Scintillating tiles with SiPM readout in low-radiation regions of CE-H

Key Parameters:

- HGCAL covers $1.5 < \eta < 3.0$
- **Full system maintained at -30°C**
- **~600m²** of silicon sensors
- **~500m²** of scintillators
- 6M Si channels, 0.5 or 1.1 cm² cell size, 400k scint-tile channels ($\eta-\phi$)
  - Data readout from all layers
  - Trigger readout from alternate layers in CE-E and all in CE-H
- ~28000 Si modules (incl. spares)

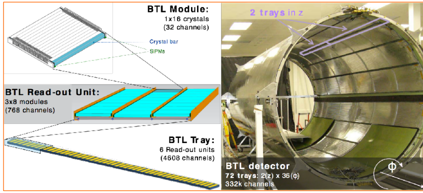


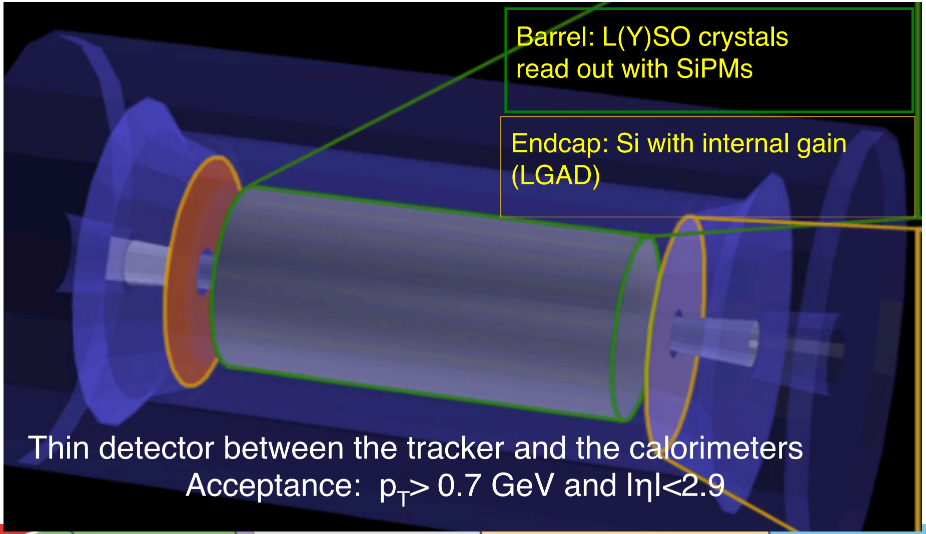
Electromagnetic calorimeter (**CE-E**): **Si**, Cu/CuW/Pb absorbers, 28 layers, 26 X_0 & ~1.7λ
Hadronic calorimeter (**CE-H**): **Si** & **scintillator**, steel absorbers, 24 layers, ~9.0λ

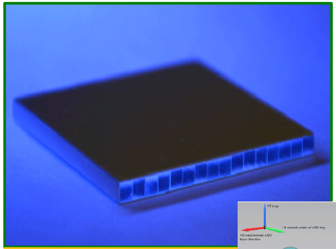
CMS Mip Timing Detector (MTD)*

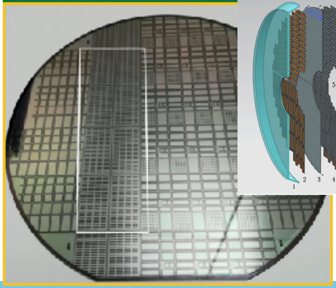
* TDR in preparation (submission to LHCC on March 29)

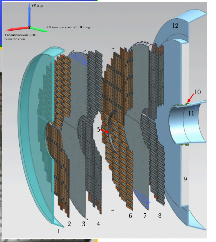
- **Significant addition to the HL-LHC program**
  - Recover Phase-1 purity of vertices with 4-dimensional tracking
  - Unique discovery potential for Long Lived Particles
  - Extended potential for Heavy Ion physics through particle identification
- **20-30% increase in effective integrated luminosity**
  - Leveraging gains the full pseudo-rapidity coverage
  - Across a wide range of observables and across the HL-LHC program







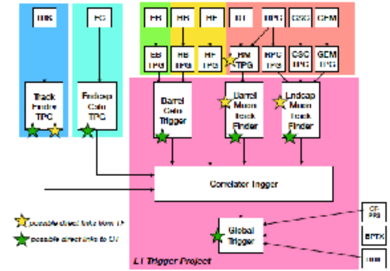




L1-Trigger Upgrade*

- Tracks in the L1 trigger at 40 MHz
- ≥ 50 Tbps input
- 12.5 μs latency
- Accept rate 500/750 kHz at 140/200 PU

* TDR in 2020



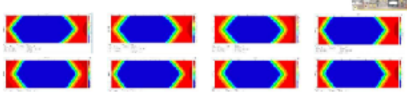
- ATCA boards under investigation
  - 60 or 96 I/O, 16-25Gb/s optics
- Algorithms integrated into L1 emulator sequence
  - Including EC trigger primitives, L1 tracks, PFlow for track candidates
- Initial FW implementation of PFlow algorithms in demonstrators
  - Use 30% of LUTs- Work starting on Machine Learning implementation

More than 75% of algorithms exist in f/w

APx consortium:

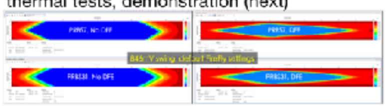
- Rev A PCB delivered in late 2018
- First board assembled in Jan19
- Link test 28GB/s successful (40 out of 76 links)
- ELM-IPMC-ESM supporting APd1
- Ongoing: more testing HLS demonstration (next)

- APd1 Rev A PCB
- VU9P FPGA
- ZYNQ-IPMC (ATCA IPMI controller)
- ELM1 (ZYNQ-based embedded Linux endpoint)
- ESM (GbE switch)
- 2 of 19 28G Firefly positions loaded



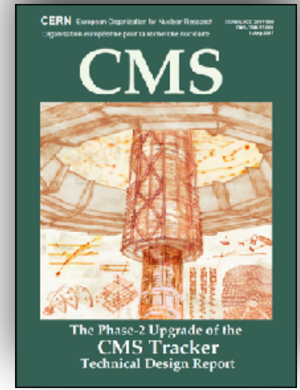
Serenity consortium:

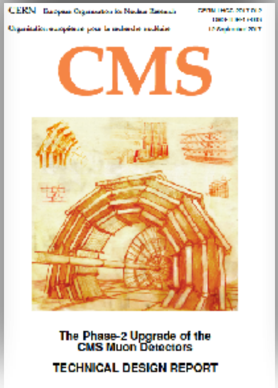
- ATCA Blade V1.1 available
- Daughter Cards Tested & Working (others submitted)
- Successful 25 GB/s link tested
- lpGPT protocol tested ok
- Ongoing: Zync/ComExpress, thermal tests, demonstration (next)

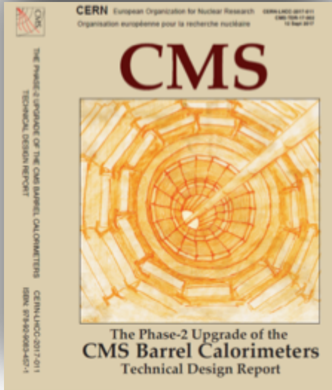


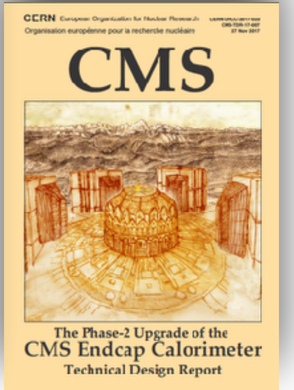
CMS HL-LHC TDRs

Completed









Planned

L1 Trigger

The Phase-2 Upgrade of the CMS Tri

Interim Report to the LHCC

CMS Collaboration

2020

DAQ/HLT

Interim Technical Design Report

for the CMS Phase-2 DAQ Upgrade

CMS Collaboration

2021

MTD

TECHNICAL PROPOSAL FOR A MIP TIMING DETECTOR IN THE CMS EXPERIMENT PHASE 2 UPGRADE

in Collaboration Wide Review

2019

BRIL

2020/2021

Plus
- PPS (LOI)
- Computing

CERN/CMS Project Approval Process (Like Critical Decisions)

Four <u>STEP</u> definition/review process:

1. Technical Proposal defines the overall scope and cost for the entire upgrade programme, with the possibility to maintain different options which may depend on technical issues and/or on funding availability.
2. The detailed technical design reports (TDR) for subsystems are reviewed individually, with the requirement that each fits in the overall approved plan for scope and cost (Project Baseline).

We are here
MTD TDR Apr'19

3. The final design and construction readiness of the major detector components are reviewed (Engineering Design Review - EDR), as well as the installation plan (Start of Construction).
4. Operations readiness reviews held to evaluate the capability of the completed detectors to provide the expected performance and mark the end of the construction project. (Start of Operations or Project Completion).

CERN/LHCC Management, Oversight, and Review

- LHC Committee (**LHCC**) reviews each the Technical Proposals for the physics case; conceptual design, including options; and the cost envelope
  - This review includes a request for "scoping" options to adjust to the realities of costing and funding
- LHCC reviews the TDRs for Technical Scope and feasibility, using some reviewers external to the LHCC, submits questions, and
  - if it approves the scope and technical solution, authorizes the project to submit its costs to the Upgrade Cost Group (**UCG**), which follows a similar process to evaluate the cost, schedule, and risks.
- When the LHCC and UCG reviews are passed, the Research Board (RB) approves the project
- When the ensemble of projects is approved, it is sent as a package to the **RRB** for to approve final financial obligations
- MoUs can be written and construction can start

US experts are on the LHCC, UCG, and RRB -- the US is central to the process!

Upgrade Project Status

- TDRs for the Tracker, HGCAL, Muons and Barrel Calorimeters have been reviewed by the **LHCC** and the costing has been reviewed by the Upgrade Cost Group (**UCG**).
  - MTD is starting this process now. The MTD TDR is in CMS internal review.
- The global CMS **Money Matrix** for the HL-LHC upgrades was approved at the **RRB** in October 2018.
- Progress and milestones for the post TDR upgrade projects will be followed by the new Phase-2 Upgrade Cost Group (**P2UG)** process. (The first session is in May 2018)
- Upgrade **MOUs** are under development.
  - MOU drafts are **nearly finalized** for projects that have approved TDRs. (Tracker, HGCAL, Muons, Barrel Calorimeters)
- **CMS Upgrade Coordination and Technical Coordination monitor the projects and organize internal reviews of all CMS Phase-2 Upgrade projects for HL-LHC.**

Upgrade Reviews

CMS Technical Coordination and Upgrade Coordination reviews*

Technical Design Reviews - submit TDR - **LHCC/UCG step 2**

Annual Reviews - monitor progress - In addition, there will be LHCC Phase-2 (P2UG) review sessions twice per year to monitor progress of approved projects.

Engineering Design Reviews **EDR** (comprehensive), Electronic System Reviews (can happen at a later stage for backend components) - launch production - **LHCC/UCG step 3**

Engineering Change Review (validate design changes)

Procurement Readiness Review (launch large orders, can be before EDR)

Manufacturing Progress Review

Installation Readiness Review

* Panels include engineers in different areas and external experts depending on reviews - reports are submitted to System, TC-UC and presented to the CMS MB and public meetings - System answers and proposed actions are followed up by panel and SMs and presented at UPSO and USG meetings

- **CMS Upgrade Coordination and Technical Coordination monitor the projects and organize internal reviews of all CMS Phase-2 Upgrade projects for HL-LHC.**

CMS Phase-2 Upgrade Organization

Upgrade Support Project Office

UTC, UEOC, URM, UPO, UPSG

Upgrade Project Coordinator and deputies

Cent. Coord.
- Off./Comp.
- PPD Coord.
- Trigger Coord.
- Run Coord.

Upgrade Systems SUC and STC
- Tracker
- Barrel Calorimeters
- Endcap Calorimeter
- Muons
- MIP Timing Det.
- BRIL
- L1-Trigger
- DAQ/HLT

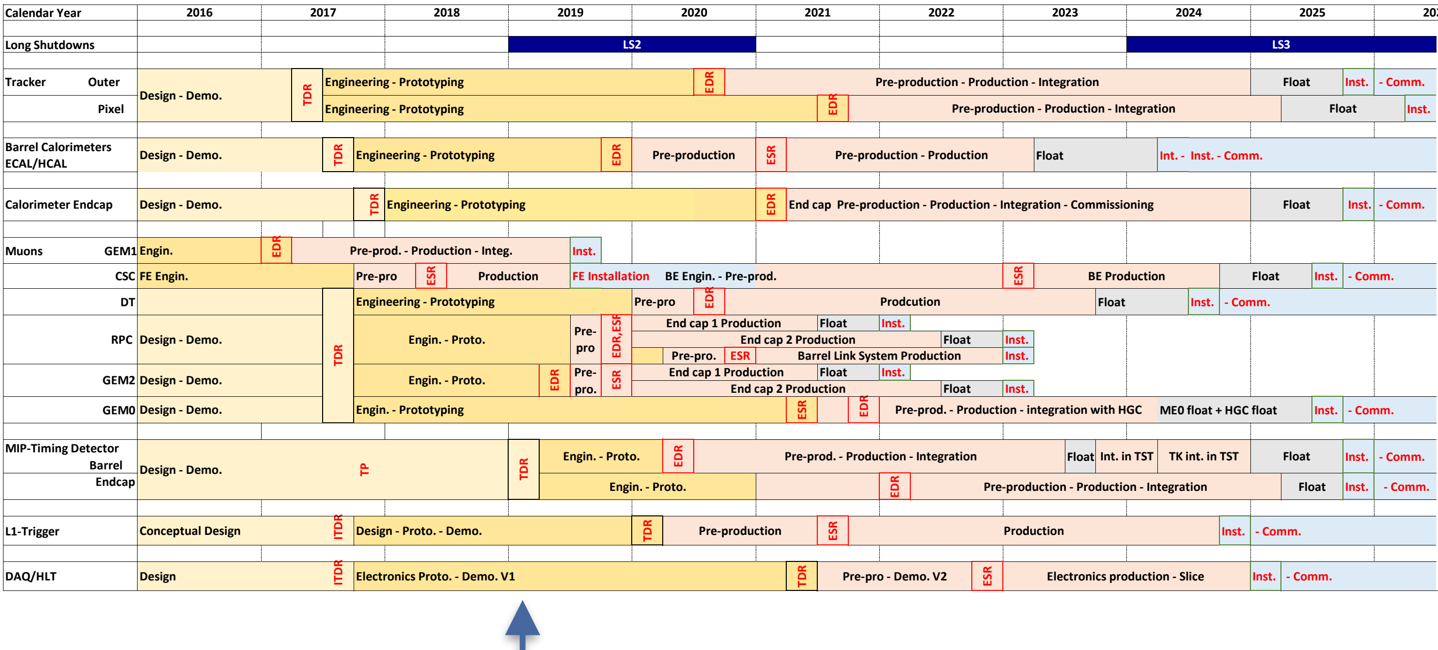
Cross-System Working Groups
- Performance Studies*
  UPSG convener(s)
- Electronics and Online Systems**
  UEOC + convener(s)
- Detector Interfaces and Integration**
  UTC + convener(s)

* Joint with Physics Coord
** Joint with Tech. Coord

Upgrade Steering Group
- Upgrade Project Office
- Cross System working groups
- Upgrade Systems
- Central Coordination Contacts

* Phase-2 Offline and Computing Upgrade is under Offline and Computing Coordination

CMS Master Schedule



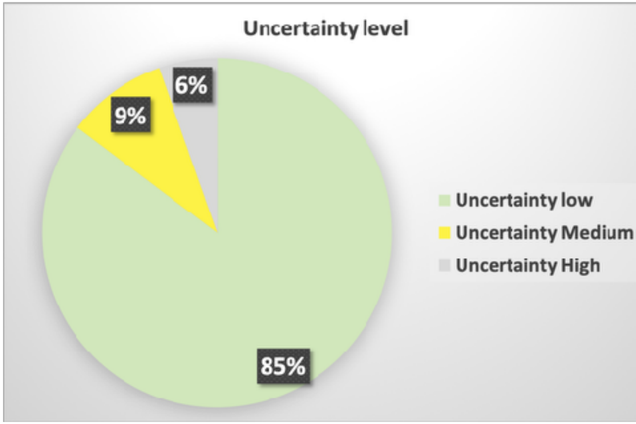
The schedule is currently under review in advance of our P2UG review in May, however we don't expect any major changes to this schedule before the review. The P2UG will continue to track the major milestones of the LHCC approved projects.

CMS Money Matrix as shown to the RRB (October 2018)

CMS Phase 2 Money Matrix (in kCHF) - RRB, 29 October 2018									
FA/ Subsystem	EC-CALO	Barrel - CALO	Muons	Tracker	MIP-TD	BRIL	TDAQ	Common Fund	Total Phase-2
CORE Costs (kCHF)	67,127	13,255	25,187	111,900	15,796	2,600	18,500	25,000	279,365
Austria	900			800				326	2,026
Belgium FNRS			100	4,800				489	5,389
Belgium FWO				5,000				417	5,417
Brazil FAPESP				1,290				127	1,417
Brazil FINEP/RENAFAE								380	380
Bulgaria			380					161	541
CERN	21,500	2,000	1,524	19,500		1,200	4,500	1,322	51,546
China	900		1,350				500	254	3,004
Colombia			80					72	152
Croatia	1,380							118	1,498
Cyprus								127	127
Egypt			200					51	251
Estonia							522	54	576
Finland			151	1.100	1,000			236	2,487
France-CEA	1,000	1,500			500			308	3.308
France-IN2P3	6,400		500	4.600				924	12,524
Germany BMBF			1,920	9,450				1,196	12,566
Germany Helmholtz				9,107			600	604	10,211
Greece	350			1,400			1,000	326	3,076
Hungary			225	300	150	225		181	1,081
India	1,877	170	1,383	2,000			260	698	6,387
Iran			1,390					145	1,535
Ireland								36	36
Italy		1,900	5,150	14.000	3,500		300	3,007	27,857
Korea			2,056					502	2,518
Lithuania							346	36	384
Malaysia	870							81	951
Mexico			1,000					189	1,189
New Zealand						70		36	106
Pakistan			580	1,600				38	2,188
Poland							300	272	572
Portugal	440	490			910			109	1,949
RDMS CMS-Russia	8,200		410			350		1,522	10,482
Serbia		80						54	134
Spain			1,300	1.200	200		100	779	3,779
Switzerland		2,400		9.100	1,000			707	13,207
Taipei	2,600							272	2,872
Thailand	100							54	154
Turkey	2,094							217	2,311
United Kingdom	3,500	500		2,500			500	1,033	8,033
USA-DOE	14,500		2,608	13,600	5,000		3,886	5,431	45,205
USA-NSF		4,184	2,230	12,810			900	1,381	21,516
USA-DOE-NP							6,306	626	6,930
Ecuador								36	36
Montenegro	190							36	226
Sri Lanka			760					72	832
Latvia	380							36	416
Qatar			300						300
Funding (kCHF)	67,251	13,243	25,937	114,277	12,360	1,845	18,811	25,035	278,758
Uncertainty low	75%	98%	70%	94%	92%	81%	58%	100%	85%
Uncertainty Medium	18%	1%	23%	5%	0%	19%	9%	0%	9%
Uncertainty High	7%	1%	7%	1%	8%	0%	33%	0%	5%
Funding/ CORE Costs	100%	100%	103%	102%	78%	71%	102%	100%	100%
Funding-CORE Costs	124	-12	750	2,377	-3436	-755	311	35	-606

Colour coding
Uncertainty low
Uncertainty Medium
Uncertainty High

- ❖ Overall cost unchanged ≃ 279.4 MCHF
- ❖ Funding slightly increased ≃ 278.8 MCHF
  - Particularly with new countries/ institutes joining CMS



CMS HL-LHC Upgrade Cost and Funding status (October 2018)

CMS Phase 2 Money Matrix (in kCHF) - FB228, 21, September 2018									
Subsystem	EC-CALO	Barrel - CALO	Muons	Tracker	MIP-TD	BRIL	TDAQ	Common Fund	Total Phase-2
Funding (kCHF)	67 251	13 243	25 937	114 277	12 360	1 845	18 811	25 036	278 760
CORE Costs (kCHF)	67 127	13 255	25 187	111 900	15 796	2 600	18 500	25 000	279 365
Funding-CORE Costs	124	-12	750	2 377	-3 436	-755	311	36	-605
% (Funding/ CORE Costs)	100%	100%	103%	102%	78%	71%	102%	100%	100%
Funding-CORE Costs/ CORE Costs (%)	0,2%	-0,1%	3,0%	2,1%	-21,8%	-29,0%	1,7%	0	0
unding-CORE Costs/ Total CORE Costs (%)	0,0%	0,0%	0,3%	0,9%	-1,2%	-0,3%	0,1%	0,0%	-0,2%
Uncertainty low	71%	98%	70%	94%	92%	81%	58%	100%	84%
Uncertainty medium	22%	1%	23%	5%	0%	19%	9%	0%	10%
Uncertainty high	7%	1%	7%	1%	8%	0%	33%	0%	5%

Overall cost and funding are well aligned

New contributions are arising from new institutes joining CMS

Funding engagement status improved: Green = 84%; Yellow = 10%; Grey = 6%

TDR systems are funded and are MoU agreements have been drafted

MTD is still short but has attracted new interest, CMS is strongly committed to this project

Physics case developing for HI physics has motivated a proposal to DOE-NP

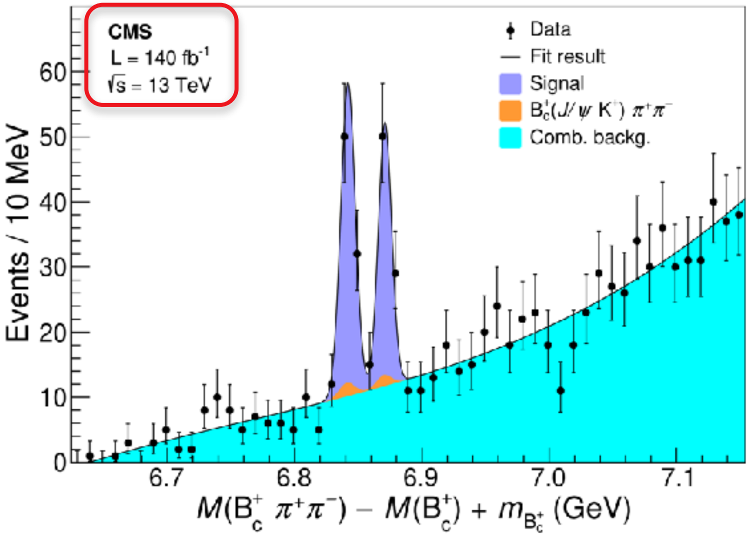
Common projects with other systems for cooling, Back-End electronics, Power Supplies, Safety System, will minimize development work has been developed

Status of CMS

First (in LHC) Run 2 paper submitted

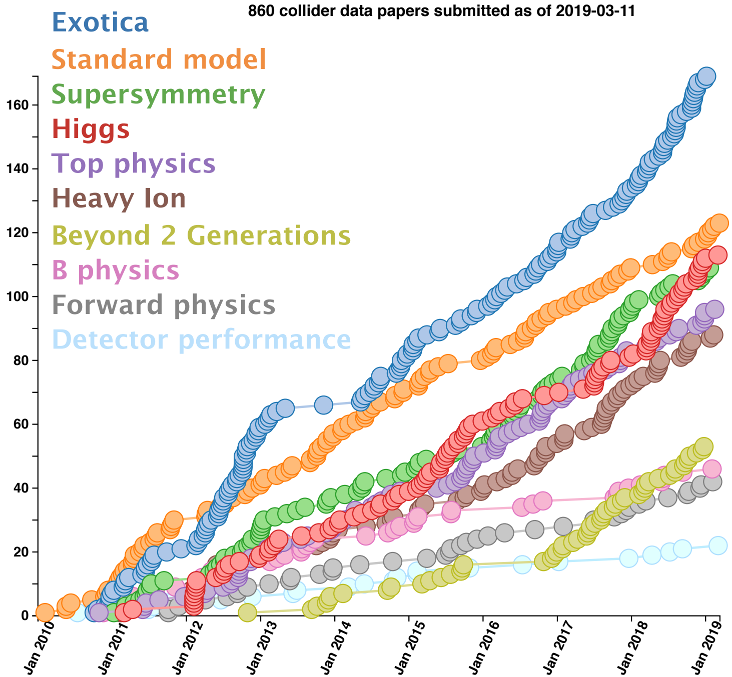
Ready with 140 fb^{-1} after two month from the end of the run is shows the detector and processing continue to performed very well

Observation of two excited B_c^+ states and measurement of the $B_c^+(2S)$ mass in pp collisions at $\sqrt{s} = 13$ TeV



Excellent tracking resolution enables us to separate cleanly the two peaks with a mass difference of 29 ± 1.5 MeV

860 collider data papers submitted



CMS submitted a record of **141 papers** in 2018. The previous record was CMS with 132 papers in 2017.

CMS is still submitting papers at a fast pace.

A challenging LS2

HCAL barrel (last phase I): install SiPM+QIE11-based 5Gbps readout

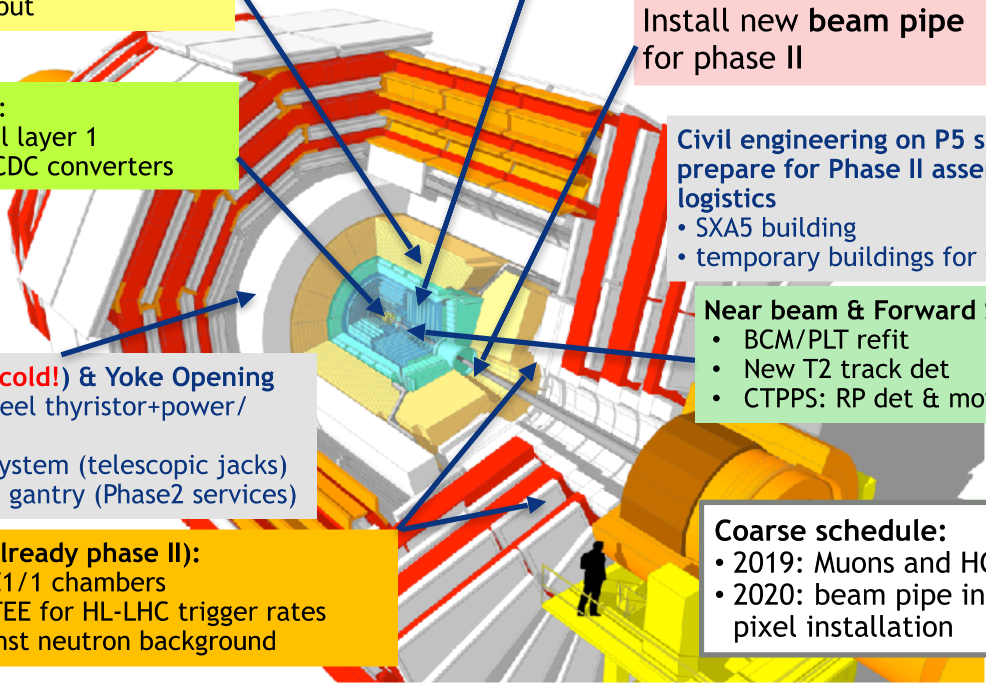
Keep **strip tracker** cold to avoid reverse annealing

Install new **beam pipe** for phase II

Pixel detector:
- replace barrel layer 1
- replace all DCDC converters

Civil engineering on P5 surface to prepare for Phase II assembly and logistics
- SXA5 building
- temporary buildings for storage/utility

Near beam & Forward Systems
- BCM/PLT refit
- New T2 track det
- CTPPS: RP det & moving sys upgrade

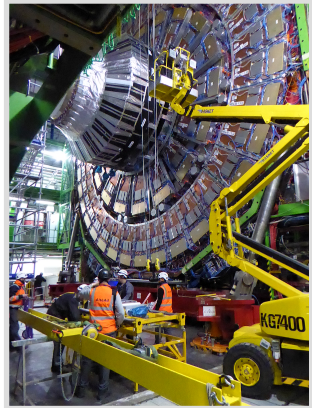


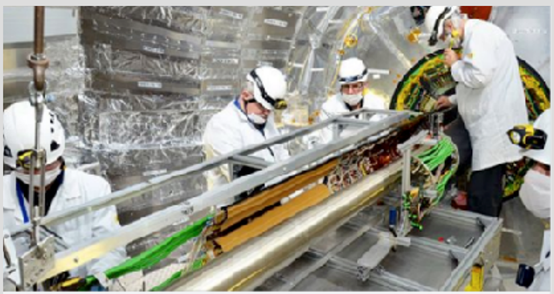
MAGNET (stays cold!) & Yoke Opening
- Cooled freewheel thyristor+power/ cooling
- New opening system (telescopic jacks)
- New YE1 cable gantry (Phase2 services)

Muon system (already phase II):
- install GEM GE1/1 chambers
- Upgrade CSC FEE for HL-LHC trigger rates
- Shielding against neutron background

Coarse schedule:
- 2019: Muons and HCAL interleaved
- 2020: beam pipe installation, then pixel installation

Status of CMS (LS2)





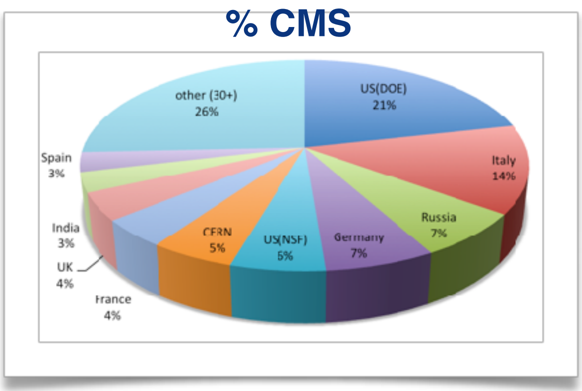
CMS.CERN
Long shutdown 2 at CMS in full swing: Pixel detector extraction | CMS Experiment

HCAL Barrel Phase 1 upgrade installation and ME1/1 Phase-2 electronics upgrade started.

LS2 work is proceeding as planned.

The US in CMS

- The US is by far the largest nation in the CMS Collaboration
  - DOE and NSF HEP funded groups taken together are 27.3%
  - DOE NP adds 1.9%
- The US groups have infrastructure and experience that give it even greater weight
- US contributions to the CMS HL-LHC upgrades have been negotiated with the CMS project managers, upgrade project coordination, spokesperson, and finance board.
- CMS could NOT continue as is if the US were to significantly reduce its level of activity.



DOE and NSF are separated in this chart.

Summary

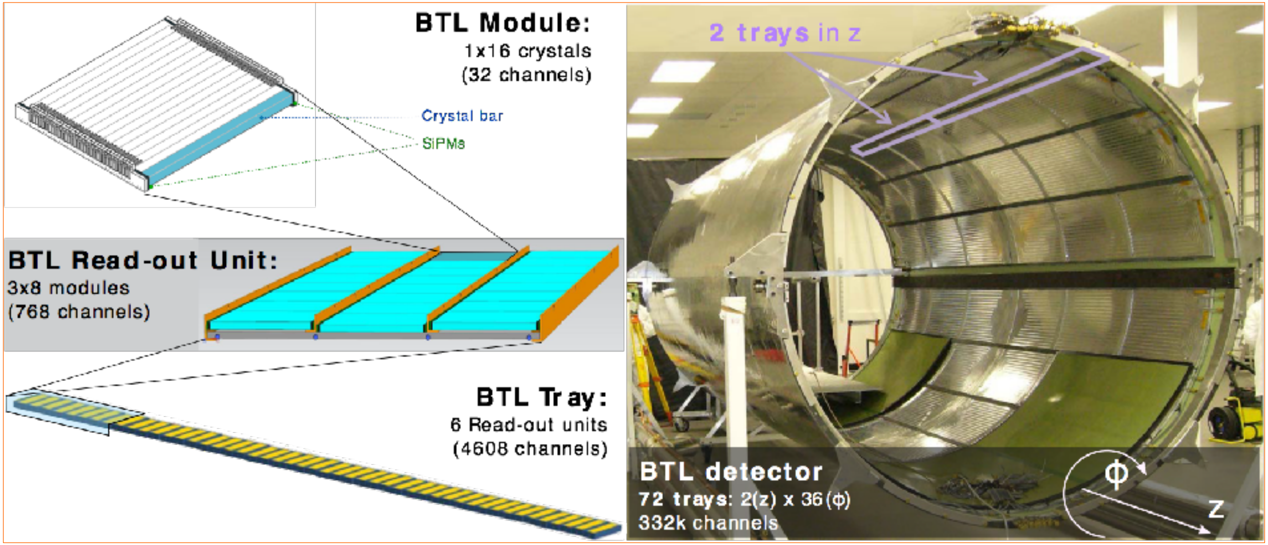
- CMS upgrades for the HL-LHC are well underway.
- The designs are well advanced and the upgrade funding model has been approved by the RRB.
- Preparations have started to prepare the infrastructure during LS2.
- The US contributions are vital to the success of the upgrades. US scientists, engineers and technicians are making important contributions.
- CMS looks forward to a strong collaboration and exciting physics opportunities through the HL-LHC era.

Thank you!

cms.cern

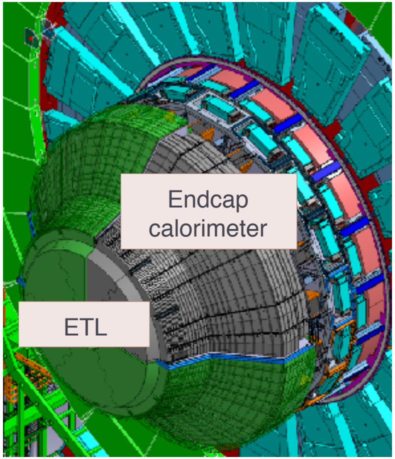
Barrel timing layer (BTL)

- **Active elements: L(Y)SO crystal bars + Silicon photon multipliers**
- **Modular structure with ~95% acceptance at |η|<1.45**
  - 72 trays (36 in φ, 2 in z) attached to the inner wall of the Tracker Support Tube
  - Segmented in Read-out Units and Modules
  - About 332k channels over 38 m^2

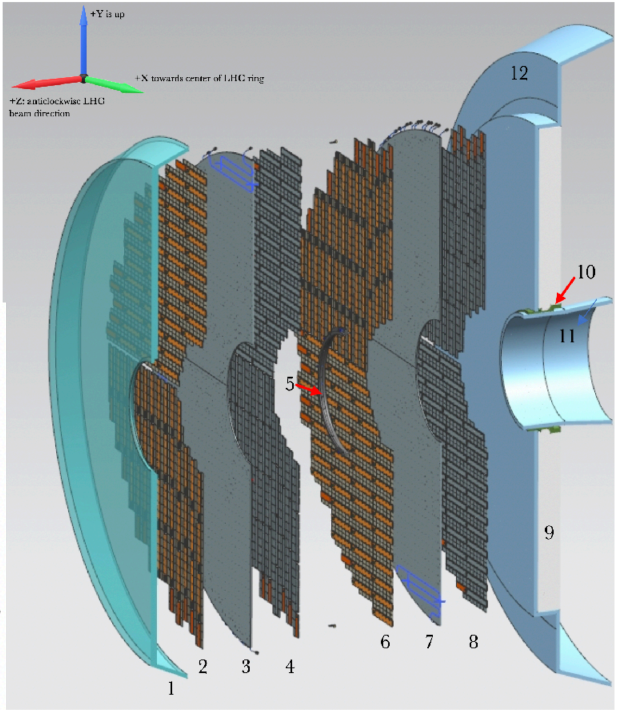


Endcap timing layer (ETL)

- Active element: Low-gain avalanche detectors (LGAD)
- Hermetic coverage at $1.6 < |\eta| < 2.9$
  - Two disks per z-side mounted on the nose of the endcap calorimeter
    - Independent cold volume and accessibility
  - About 6 million pads of 1.3x1.3 mm^2 arranged in ~9000 modules mounted on the two sides of each disk.



1: ETL Thermal Screen
2: Disk 1, Face 1
3: Disk 1 Support Plate
4: Disk 1, Face 2
5: ETL Mounting Bracket
6: Disk 2, Face 1
7: Disk 2 Support Plate
8: Disk 2, Face 2
9: HGCal Neutron Moderator
10: ETL Support Cone
11: Support cone insulation
12: HGCal Thermal Screen



CERN Review Committees

LHC Experiments Committee (LHCC)

Chairperson: Frank Simon (MPI, Munich)

Upgrade Cost Group (UCG)

The **Upgrade Cost Group** (UCG) reviews the CORE cost of Technical Design Reports (TDR). Its mandate can be found here: UCG Mandate and Composition (pdf). The UCG reports to the Research Board via the LHCC Chairman.The reports can be found in CDS via this link.
Chairperson: A.J.S. Smith (Princeton, USA)

Phase-II Upgrade Cost Groups (P2UG)

The Phase-II Upgrade Groups (P2UG) monitor the execution of the Phase II upgrade projects, verifying the technical progress, tracking the milestones, and ensuring the level of effort and managerial organization are adequate. Their mandate and composition can be found here (url).
Chairperson:
CMS: Marcel Demarteau (ANL, US)

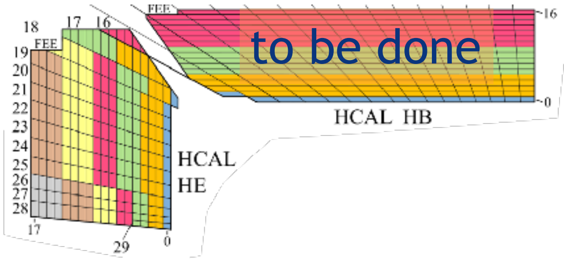
CERN/CMS Core Costing

- **"CORE costs" are defined as M&S (materials and services) costs for the production phase of the project.**
- **They include:**
  - Final prototype or pre-production fabrication required to validate a final design or product quality, prior to production
  - Engineering costs incurred during production at a vendor or contractor, not at a CMS member institution
  - Production fabrication and construction costs, including QA and system testing during the assembly process
  - Transportation costs, integration and installation, including costs associated with technical labor supplied at CERN for these purposes
- **Core costs do not include:**
  - R&D and prototype costs associated with developing the design
  - Costs for purchasing or building infrastructure and facilities needed by the project
  - Any labor costs at CMS institutions or support for physicists at CERN
  - Travel costs for institution personnel
- **Currency and Inflation**
  - Item costs are estimated in CHF, USD or EUR, in 2016. There is a formula for currency conversion.

Phase 1 and LS2

- Phase I CMS upgrade is almost done, and in line with the planned schedule budget, providing substantial benefits already during Run 2
  - The last Phase 1 upgrade is HCAL HB. In addition, several important operations on the detectors will be done during LS2, including the Pixel revision (DC/DC converters and Layer 1 planned replacement), several Phase 2 muon upgrades (GE1/1, CSC electronics), and beam pipe replacement

LS2 (and then Run 3 and Run 3 YETS) will see detector and infrastructure common systems upgrade or upgrade preparation that must be completed to enable detector upgrade in a 30 month LS3.



CMS information

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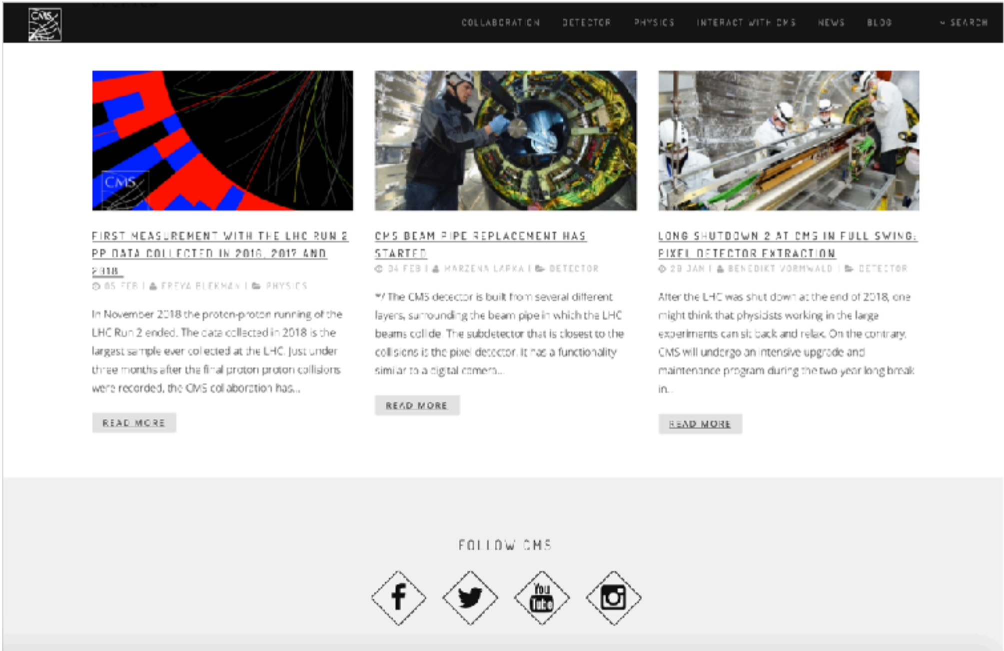

- CMS public web pages
- short articles with CMS news