CMS highlights

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July 11, 2024

Overview

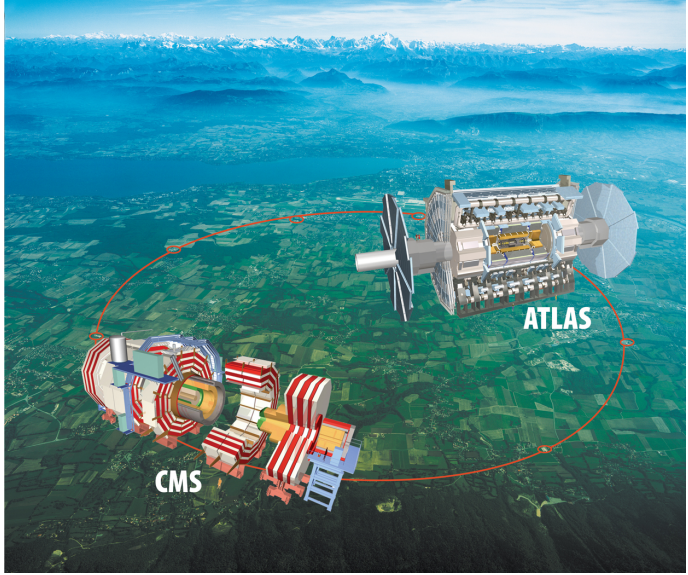
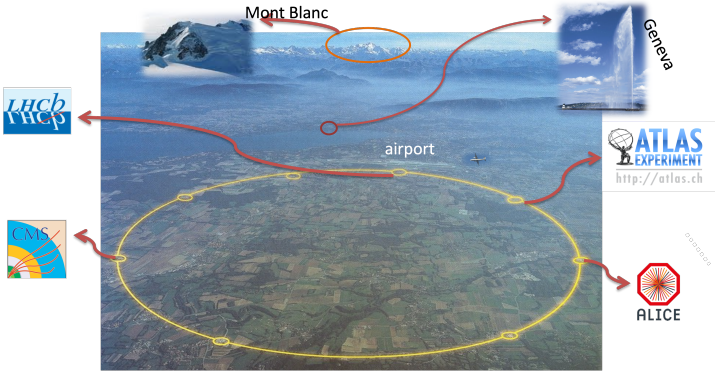
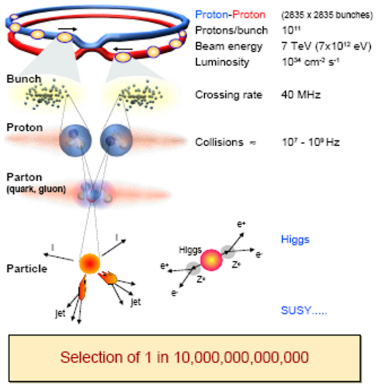


Image from CDS CERN server

LHC


Mont Blanc
Geneva
airport
LHCb
ATLAS
EXPERIMENT
http://atlas.ch
CMS
ALICE

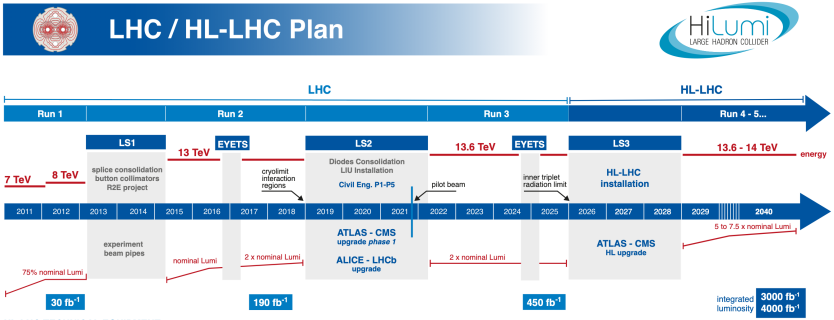
CERN CDS


Proton-Proton (2835 x 2835 bunches)
Protons/bunch 10^{11}
Beam energy 7 TeV (7×10^{12} eV)
Luminosity 10^{34} cm^{-2} s^{-1}
Bunch
Crossing rate 40 MHz
Proton
Collisions ≈ 10^7 - 10^9 Hz
Parton (quark, gluon)
Particle
jet
jet
Higgs
Z
Higgs
SUSY.....
Selection of 1 in 10,000,000,000,000

LHC Operations

Amazing LHC performance! Thaks to the LHC Collaboration pp Run-3 has collected 100 fb^{-1}

- 2010−2012: Run−1 7/8 TeV. Collected by CMS $\sim$ 27 fb^{-1}
- 2015−2018: Run−2 13 TeV. Collected by CMS $\sim$ 150 fb^{-1}
- 2022−2025: Run−3 13.6 TeV. Collected by CMS so far $\sim$ 116 fb^{-1}



High Luminosity Project

Run3 Event at 13.6 TeV: New world record!

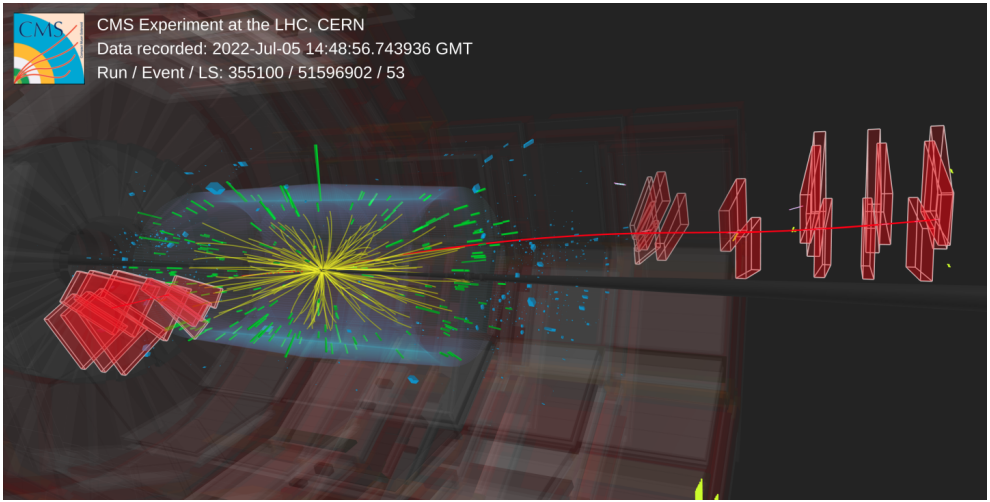
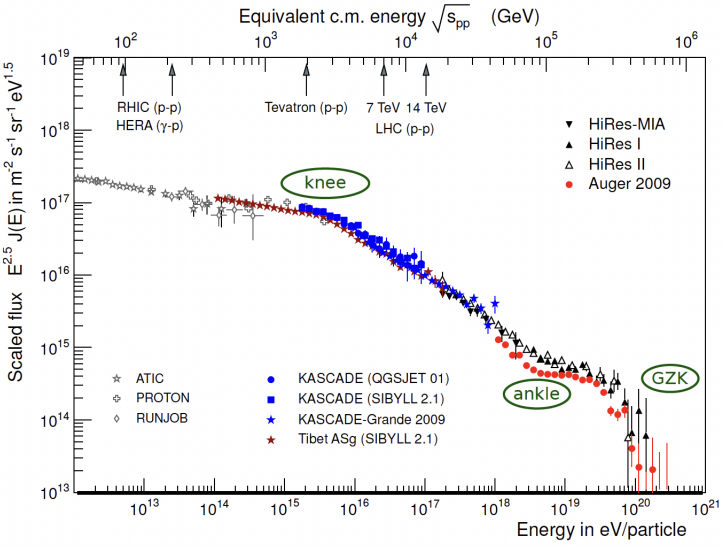


Image from CMS News

Cosmic Ray Flux

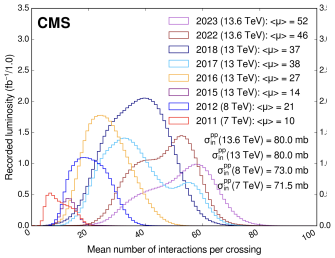


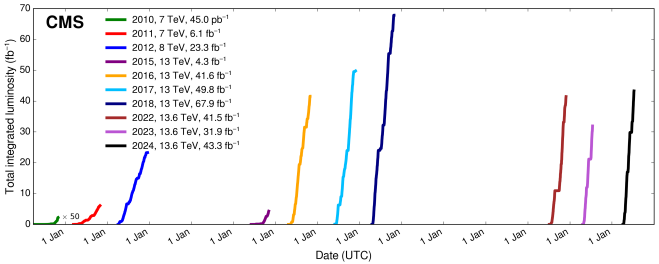
LHC approaches the energy levels of cosmic rays at the "knee" region, while the Future Circular Collider (FCC-hh) could cover the "ankle" region.

C. Baus, CERN-THESIS-2015-222

CMS Status

LHC restarted on July 5th,2022. Expected to deliver $240-250$ fb^{-1} for 4-year Run. [5][3]

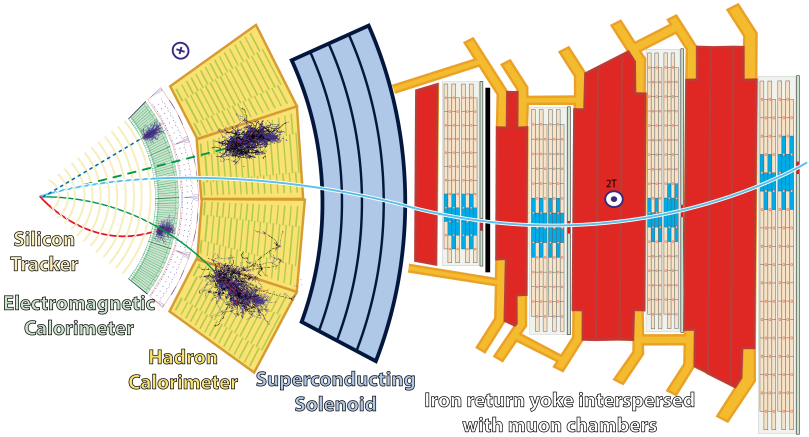




- Over 100 fb^{-1} delivered at 13.6 TeV
- More than 97% data taking efficiency. [2]

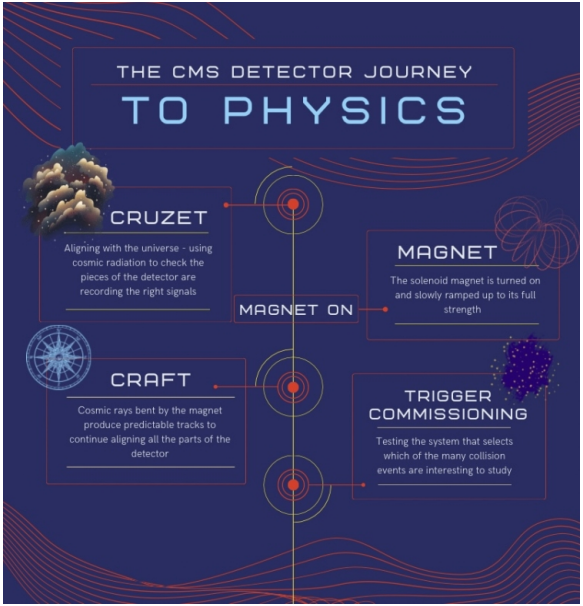
CMS Luminosity Public Results

CMS


Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
2T
Iron return yoke interspersed with muon chambers
Muon
Electron
Charged hadron (e.g. pion)
Neutral hadron (e.g. neutron)
Photon

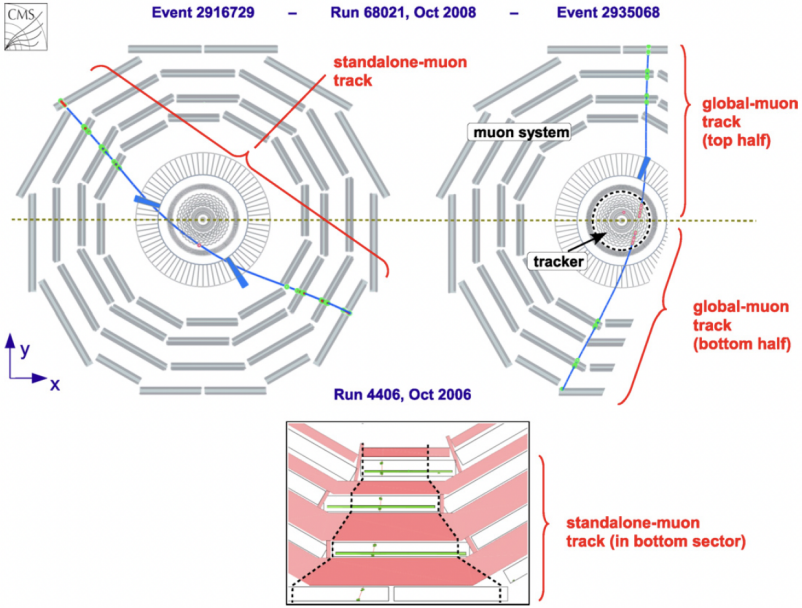
CERN CDS

RUNs



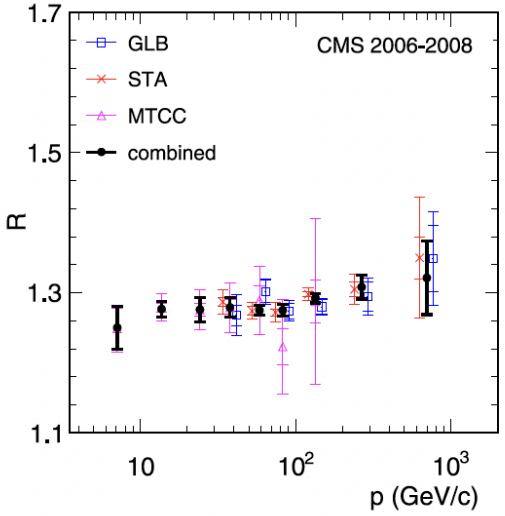
CMS Communications

Cosmic



Physics Letters B 692 (2010) 83–104

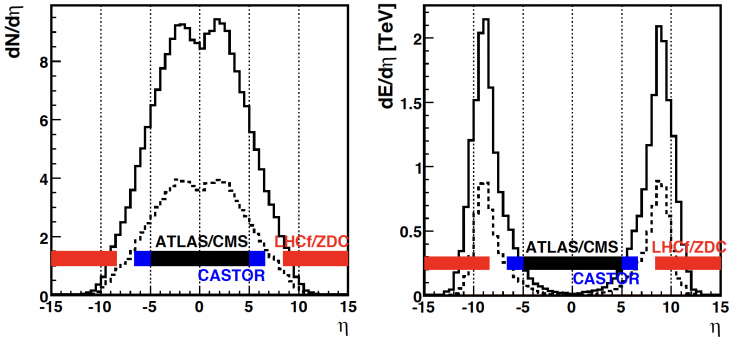
Ratio of atmospheric muons



Flux ratio of positive- to negative-charge cosmic ray muons, as a function of the muon momentum and its vertical component, using data collected by the CMS experiment in 2006 and 2008. The result is in agreement with previous measurements by underground experiments. This is the most precise measurement of the charge ratio in the momentum region below 0.5 TeV/c. It is also the first physics measurement using muons with the complete CMS detector.

Physics Letters B 692 (2010) 83–104

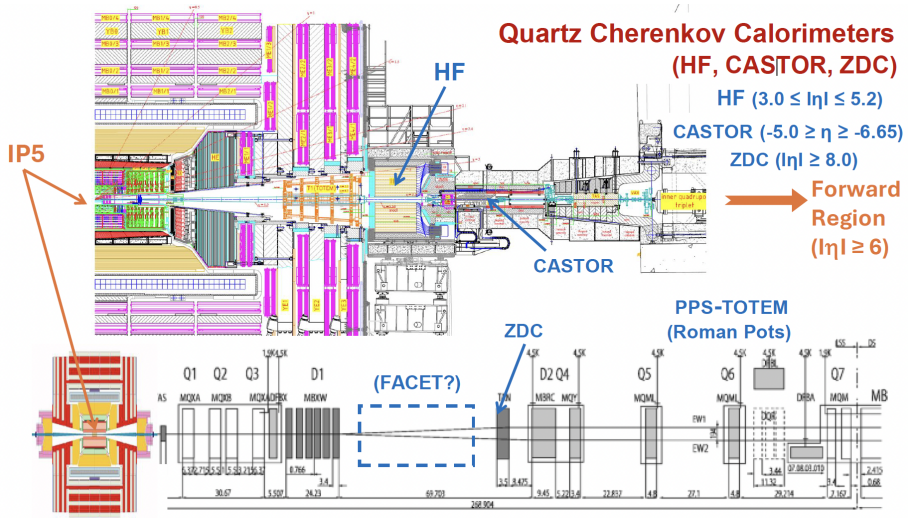
LHC: Multiplicity and Energy Flux at 14TeV



JPS Conf. Proc. 15, 011001 (2017)

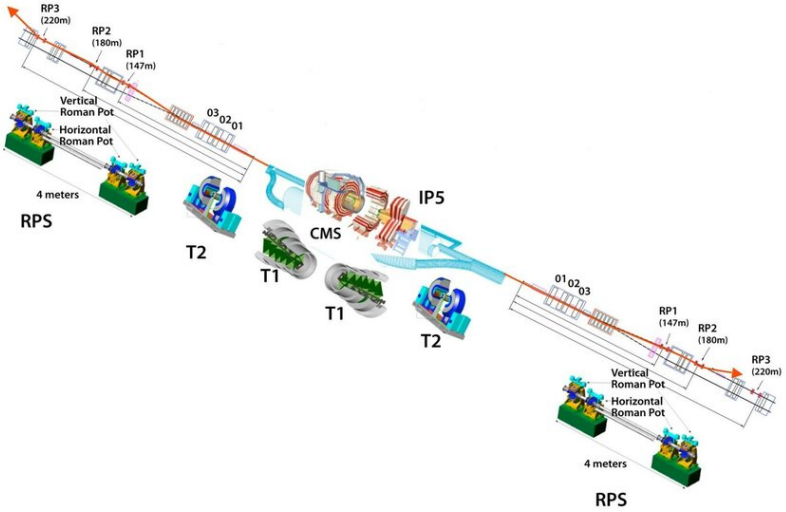
Most energy is directed into the very forward region, crucial for EAS.

CMS Forward detectors



Also Penzo, QCD24

TOTEM


RP3
(220m)
RP2
(180m)
RP1
(147m)
Vertical
Roman Pot
Horizontal
Roman Pot
4 meters
RPS
03 02 01
T2
T1
CMS
IP5
T1
T2
01 02 03
RP1
(147m)
RP2
(180m)
RP3
(220m)
Vertical
Roman Pot
Horizontal
Roman Pot
4 meters
RPS

TOTEM

TOTEM (TOTal cross section, Elastic scattering and diffraction dissociation Measurement at the LHC)

- σ_{TOT}^{pp} using a luminosity independent method (optical theorem) simultaneously measuring:
  - N_{el} down to -t ~10^{-3} GeV^2
  - N_{inel} with losses < 3%

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \frac{(dN_{el}/dt)_{t=0}}{(N_{el}+N_{inel})}$$

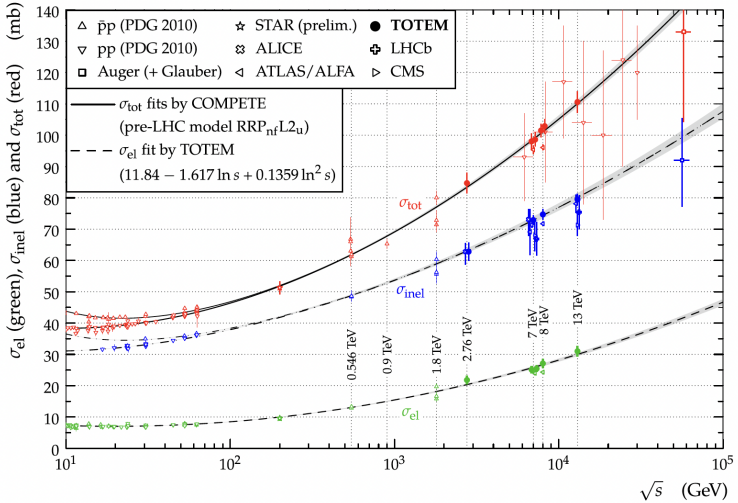
$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \frac{d\sigma_{el}}{dt}|_{t=0}, \quad \sigma_{inel} = \sigma_{tot} - \sigma_{el}$$

- Elastic pp scattering in the range $10^{-3} < |t| \sim (p\theta)^2 < 10$ GeV^2
- Soft diffraction (SD and DPE)
- Particle flow in the forward region (cosmic ray MC validation/tuning)
- To access to the smaller t-value region, the colliding beams must have a beam divergence of not more than a few μ-rad. This can be obtained by either **increasing the beta function value, β^***, or by reducing the beam emittance, ε (beam divergence = $\sqrt{\varepsilon/\beta^*}$)

F.S. Cafagna ICRC2019

N_{el} is measured by T1 and T2 telescopes, while N_{inel} by the RomanPotsdetectors.

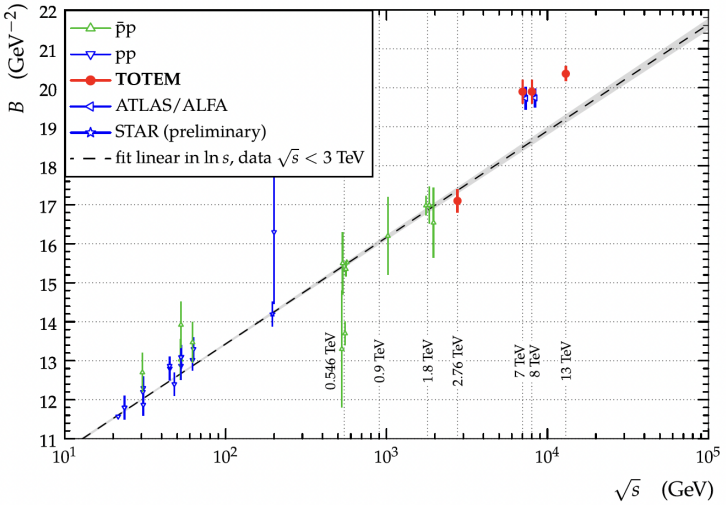
Cross-section measurements from LHC



Compilation of all the previous pp and p^-p total, elastic and inelastic measurements, together with a selected set of TOTEM measurements.

Eur. Phys. J. C (2019) 79: 103

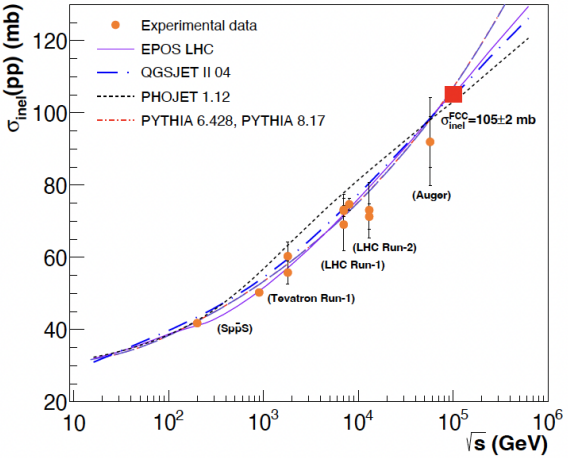
Cross-section measurements from LHC



The deviation at LHC energies of the nuclear slope (description of the angular distribution of particles) from the low energy linear extrapolation is clearly visible.

Eur. Phys. J. C (2019) 79: 103

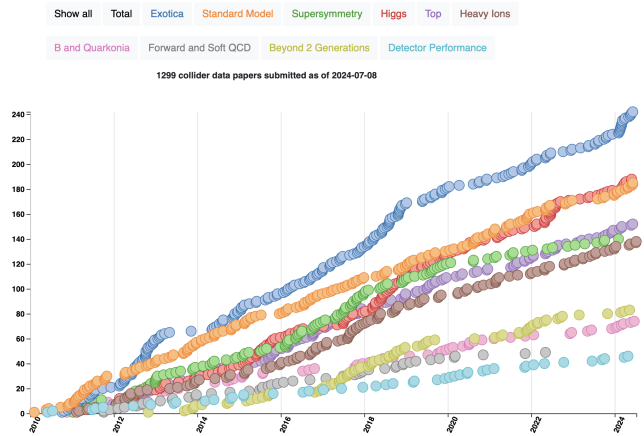
Perpectives



JHEP08(2016)170

The deviation at LHC energies of the nuclear slope (description of the angular distribution of particles) from the low energy linear extrapolation is clearly visible.

Physics results and publications

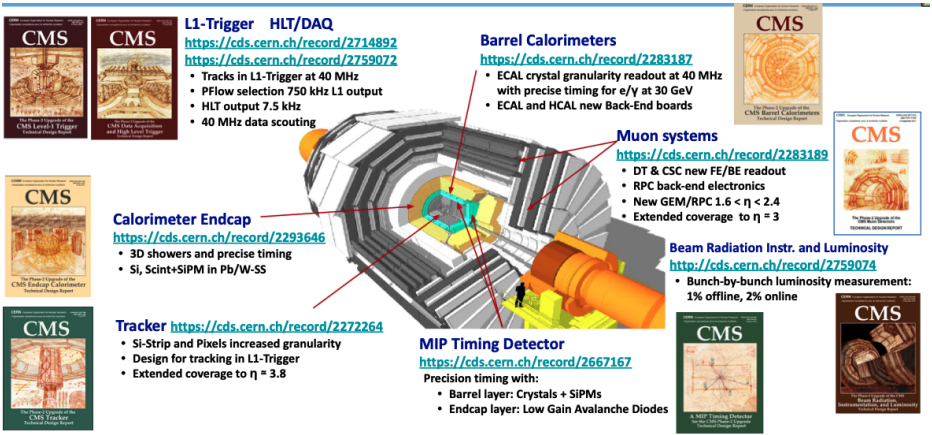


- 1299 papers on collider data published or submitted to a journal.
- Run 2 data analysis continues driven by innovative and challenging uses of the large data set.
- Run 3 data analysis foresee 100 analysis in the coming years.

CMS Publications vs Time

HL-LHC preparation

HL−LHC preparation

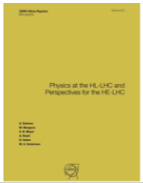


Approved PPS2 proposal: official subsystem of CMS within the HL-LHC project!

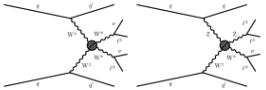
©Rizzi [1]

HL−LHC preparation

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

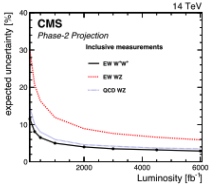


- **VBS measurement of $W^{\pm}W^{\pm}$ and WZ at HL-LHC uses leptonic decay modes of both W and Z where l = e, μ**
  - Extrapolated from full Run 2 analysis
  - Contributions of $W_L^{\pm}W_L^{\pm}$, $W_L^{\pm}W_T^{\pm}$ and $W_T^{\pm}W_T^{\pm}$ are measured in the $W^{\pm}W^{\pm}$ CM reference frame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

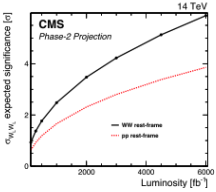


Mode	WW reference frame fraction (%)	Parton-parton reference frame fraction (%)
$W_L^{\pm}W_L^{\pm}$	10.9	7.3
$W_L^{\pm}W_T^{\pm}$	31.9	37.4
$W_T^{\pm}W_T^{\pm}$	57.2	55.3

Uncertainty for inclusive measurements

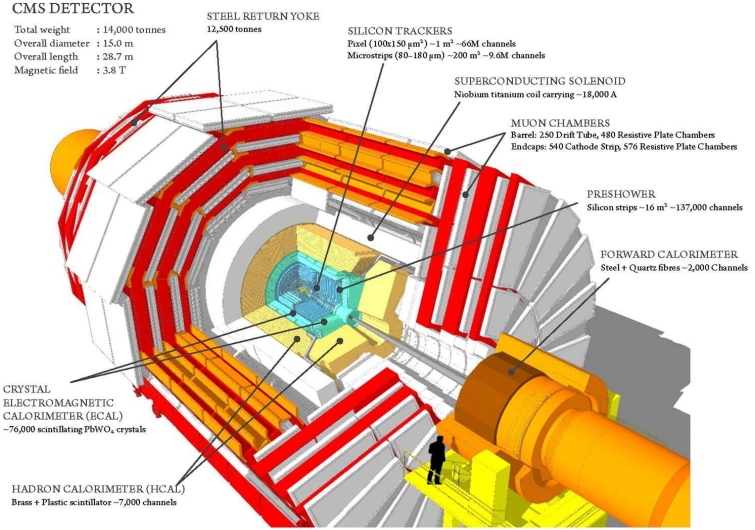


Expected significance for the detection of W_LW_L



CMS-PAS-FTR-21-001

Backup



Nature 607, 60-68 (2022)[4]

PPS2

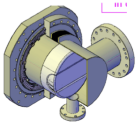
Proposal to re-install existing PPS XRPs for HL-LHC at 196m, 220m, and 234m locations

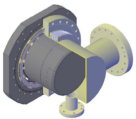
Continuation and extension of successful Run 2/3 physics program: both larger integrated luminosity, and exploring uncharted range of masses

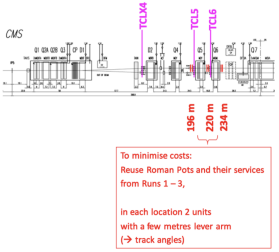
Detailed scope document and ECR prepared, following Expression of Interest published in 2021

Significant progress in defining exact locations, services, machine interfaces, costs, etc. in the past year

Designs for the relatively small “new” pieces (vacuum vessels, detector packages) prepared







Summary

- LHC results can be use to retune some basic model ingredients and improve their extrapolations to the highest energies.
- UHECR show muon excess (esp. at large axis distance): Could the heavy-Q and pQCD minijet production the couse of the muon excess?
- In any scenario the search for new physics is needed.
- Preparing for HL-LHC: new detectors to be installed.

Some references

References I

[1] CMS Collaboration Andrea Rizzi. *CMS Highlights at ICHEP*. https://agenda.infn.it/event/28874/contributions/171902/. Accessed: 2024–07-10. 2022.

[2] CMS Collaboration Anna Benecke. *CMS Status Report at the 151st LHCC Meeting - OPEN Session*. https://indico.cern.ch/event/1413315/contributions/5939332/attachments/2866065/5016561/20240529_LHCC_CMS_AnnaBenecke.pdf. Accessed: 2024–07-10. 2022.

[3] Filip Moortgat Brian Petersen. *Physics expectations for Run 3 at LHC Performance Workshop 2022*. https://indico.cern.ch/event/1097716/contributions/4618695/. Accessed: 2024–07-10. 2022.

[4] CMS Collaboration. "A portrait of the Higgs boson by the CMS experiment ten years after the discovery". In: *Nature* 607 (2022), pp. 60–68. URL: https://doi.org/10.1038/s41586-022-04892-x.

References II

[5] LHC Collaboration Mike Lamant. *LHC Accelerator: status and perspectives at ICHEP*. https://agenda.infn.it/event/28874/contributions/171905/. Accessed: 2024–07-10. 2022.