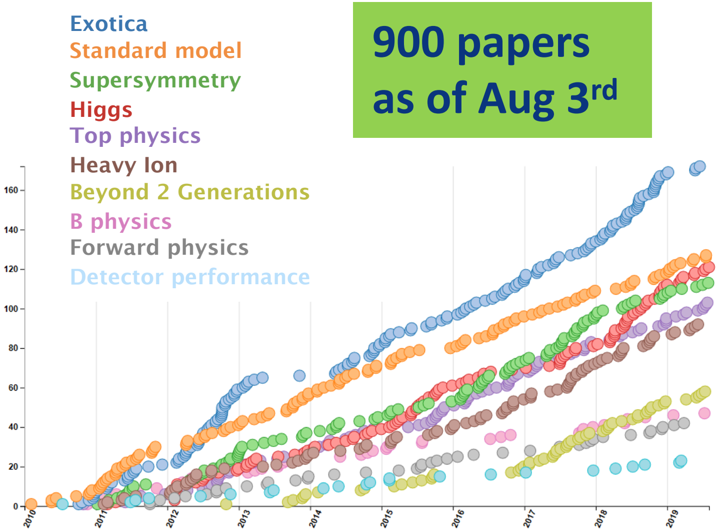
CMS, a successful collaboration looking to the future

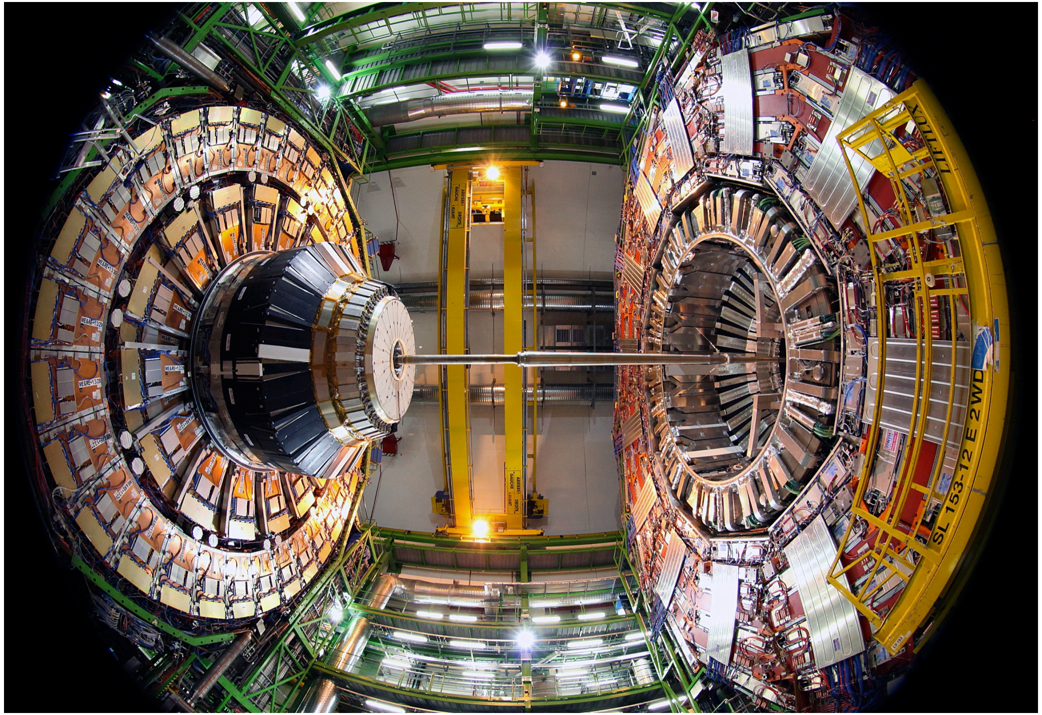
Dubna, talk for Igor Golutvin's Jubilee

8th August 2019

CMS is a successful detector and collaboration

900 papers as of Aug 3rd





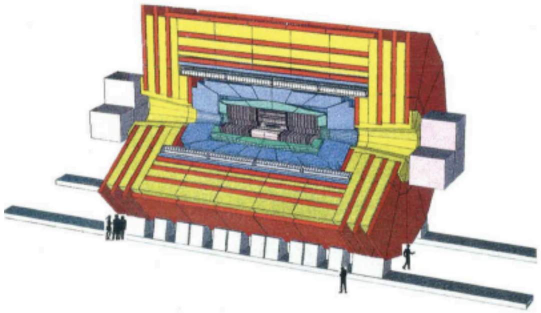
Thanks to the commitment and ingenuity of the collaboration, and **thanks to the great detector we have built**

And Igor had a big role to shape and build CMS

CERN/LHCC 92-3
LHCC/I 1
1 October 1992

LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES
CERN EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CMS
The Compact Muon Solenoid



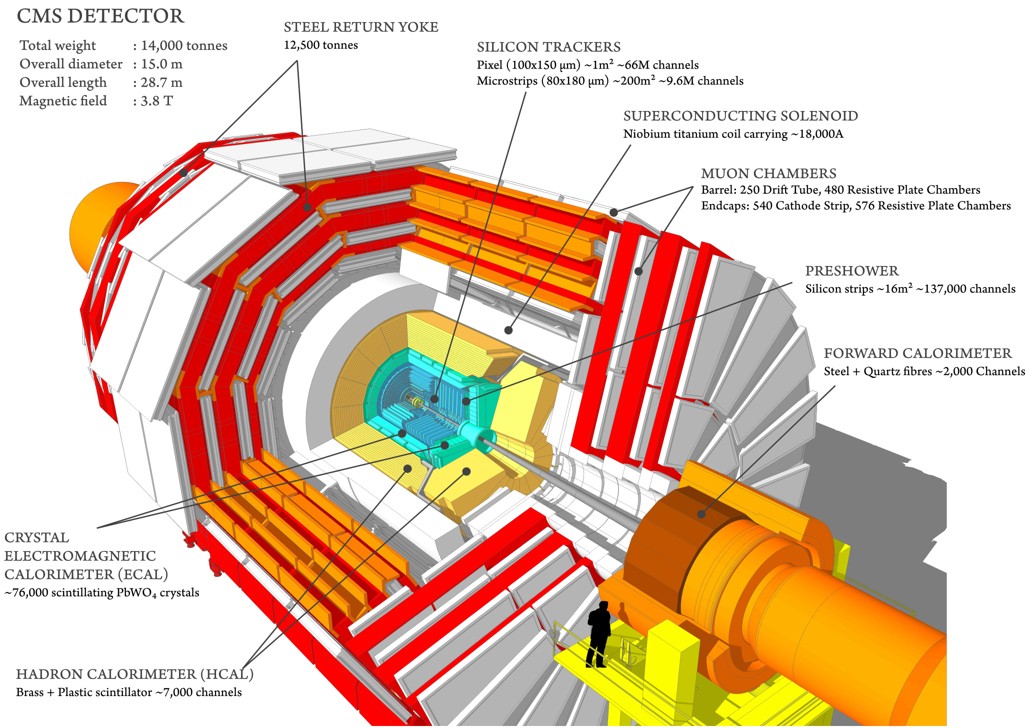
Letter of Intent

One of the founding fathers of the CMS collaboration

JINR, Dubna, RUSSIA

P. Akishin, S. Andreev, A. Bel'kov, M. Bondila, V. Chalyshev, A. Cheremukhin, N. Chernenko, B. Eidelman[6], V. Eremin[7], I. Evsikov, N. Fadeev, A. Feschenko, E. Fefelova, S. Golubykh, I. Golutvin, I. Ivanchenko, L. Ivanjutin[5], V. Ivanov, V. Kalagin, V. Kharlamov[6], A. Khassanov, A. Kotikov, Z. Kozenkova, Y. Kozlov[5], V. Krivokhizhin, A. Lanev, S. Losanu, I. Lukyanov, K. Medved, I. Merkin, V. Minashkin, P. Moissenz, A. Nogaitsev, V. Panasik, D. Peshekhonov, I. Pusinin, R. Rashevsky, I. Savin, S. Sergeev, G. Shabratova, A. Sidorov[5], G. Smirnov, N. Susova, A. Vasilesku, E. Verbitskaya[7], A. Yaremchuk[6], G. Yarygin, I. Yudin, N. Zamyatin, P. Zrelov, E. Zubarev, V. Zverolovlev[6]

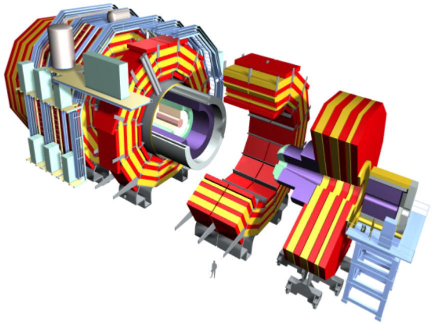
CMS, an evolving, innovative detector

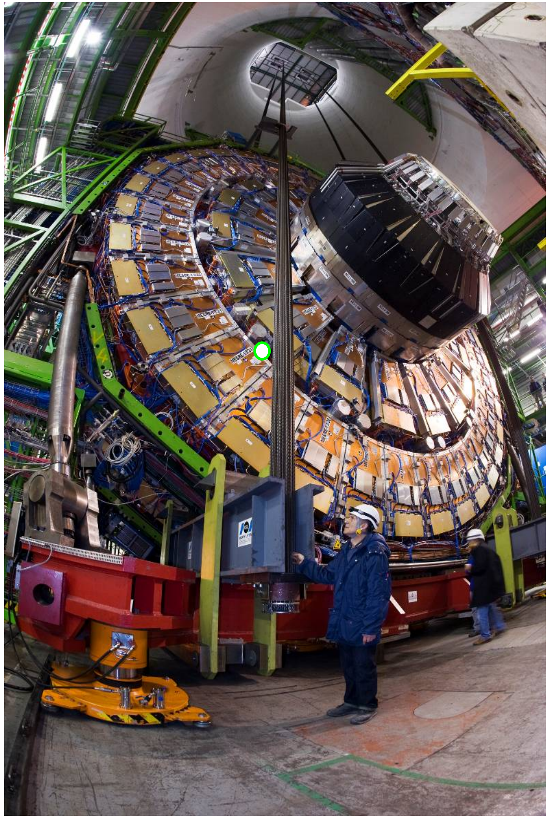


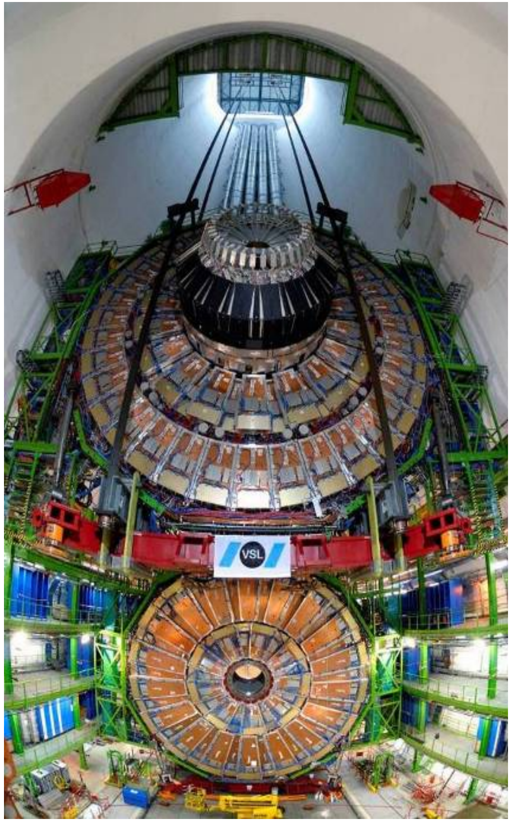
- CMS, an innovative detector from the beginning
  - Large magnet with 4T magnetic field surrounding both calorimeters
  - Full Si trackers
  - Redundant muon detectors, all with trigger capabilities
  - Commodity based High Level Trigger after the L1 trigger
  - …
- Worked extremely well, evolved in the past years and will evolve for HL-LHC keeping the characteristic innovativeness

Focus on CMS Endcaps

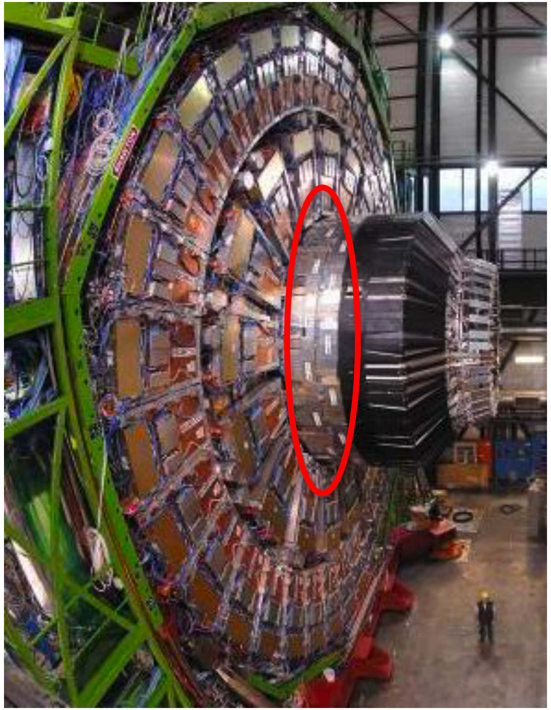
JINR made major contributions to the design, construction, installation and operation of detectors in the endcaps



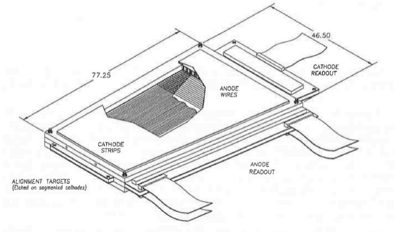




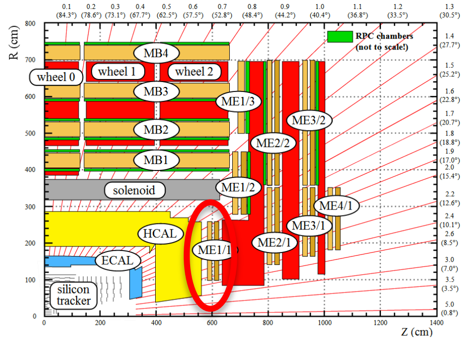
A flagship project: CSC and the ME1/1 muon detector



- CSC are the key muon detector in the endcaps contributing to the readout and trigger in particle density areas
- **Igor had a key role in the proposal to use CSC detectors in CMS,** then the chambers were produced in JINR, PNPI, Gatchina and US and have demonstrated excellent performances

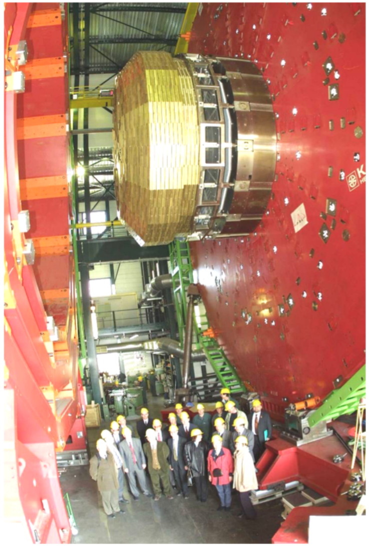


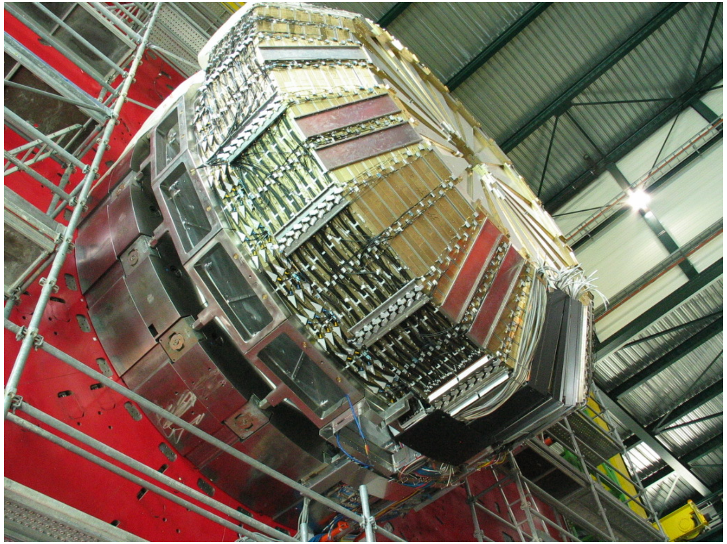
- In particular, ME1/1 were produced in Dubna, with **Igor as ME1/1 project leader**



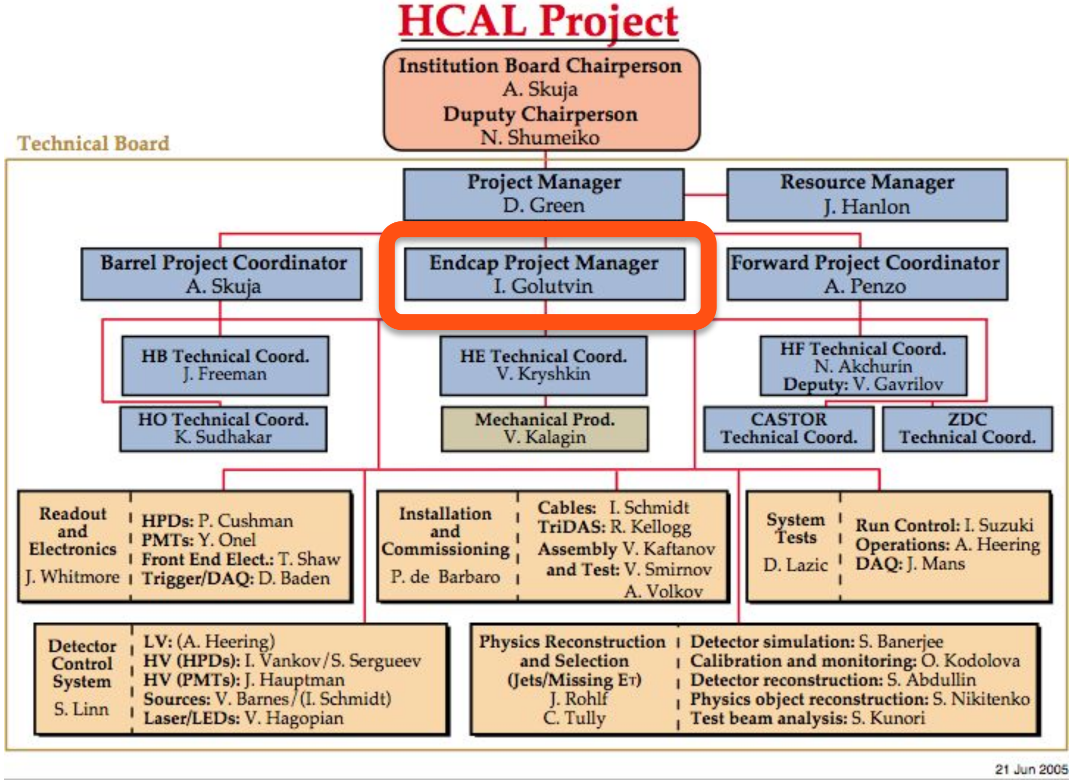
HE, another fundamental part of CMS endcaps

- Invaluable contribution of scientist and engineers from JINR in the design, construction, installation, commissioning and continuous operations of the hadron calorimeter



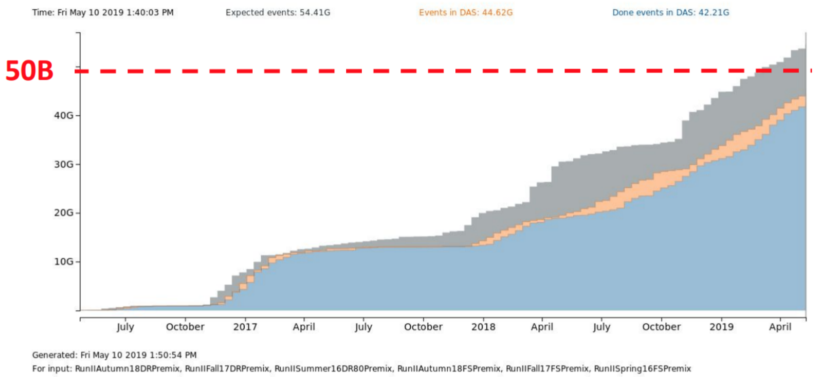


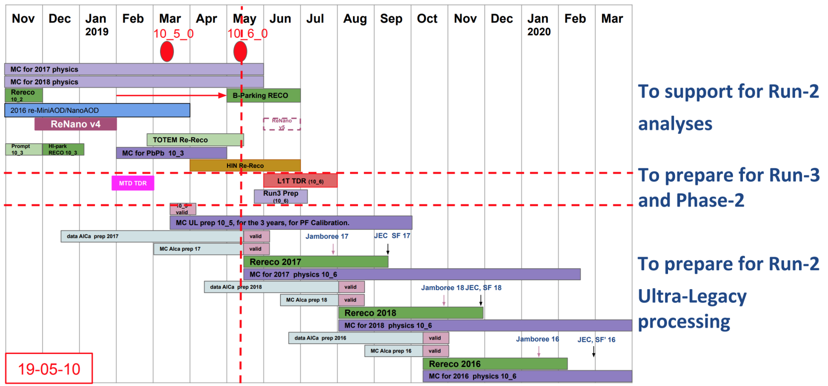
HCAL Org Chart during Installation (2005)



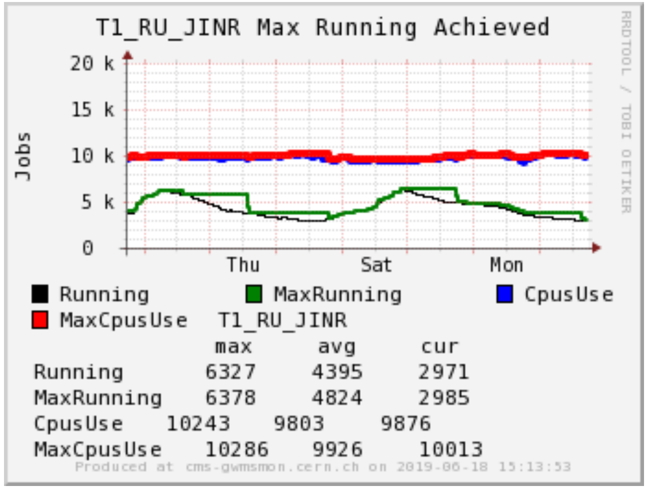
CMS, not only a detector but lot of computing and software development

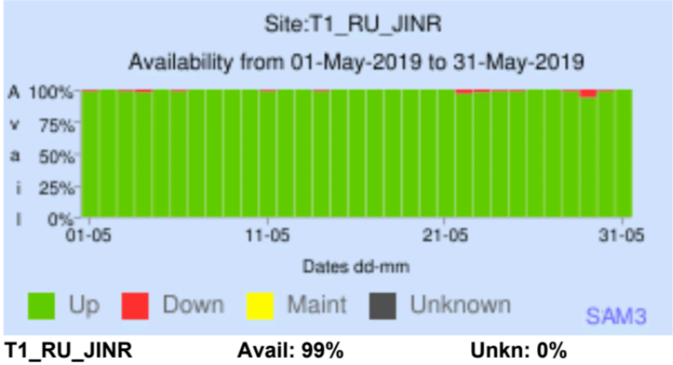
- Presently Offline + Computing systems (250kCores total) cope with
  - data taking with larger-than-expected parking and Heavy Ions throughput
  - support for analyses
  - preparation of samples for Phase-II TDRs
  - evolution of our software and services
  - preparation of 50B MC events





And JINR is one of our big computing centres



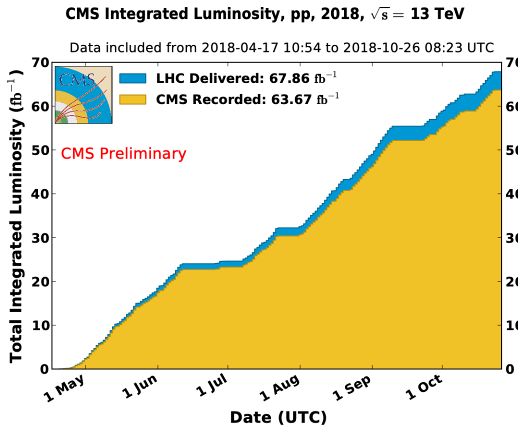


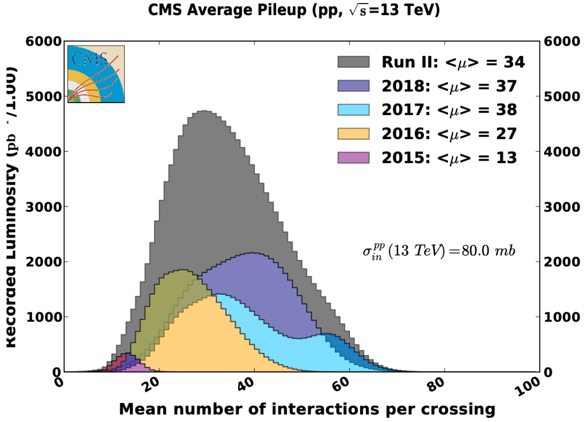
- **Igor was instrumental in initiation GRID computing for CMS in Russia**
- Now JINR T1 has an excellent availability and evolution, and a recently improved network connection
- There could be good prospect to have a more effective utilization of JINR HPC, now that CMS is migrating to heterogeneous architectures (presently mostly GPUs)

CMS data in Run 2

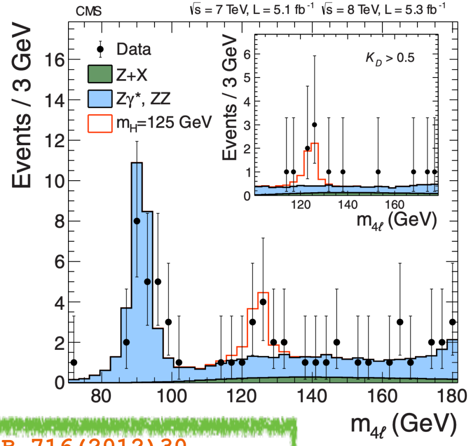
- Thanks to the excellent design, CMS managed to take data with a luminosity and pile-up a factor 2 higher than planned!
  - Reminder: Run 2 data taken with an evolving detector configuration, in particular
    - upgrade of the pixel detector to 4 layers
    - upgrade of the HCAL endcap readout (long. segmentation)

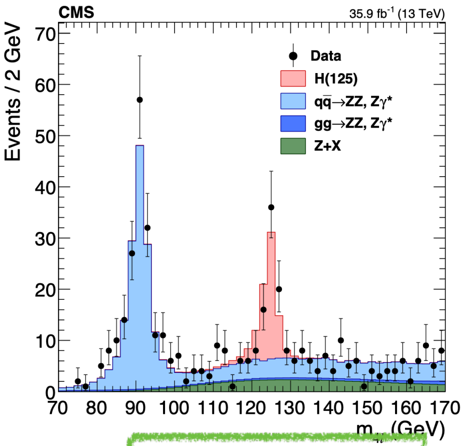
- What are we doing with this data? Just few examples in Higgs

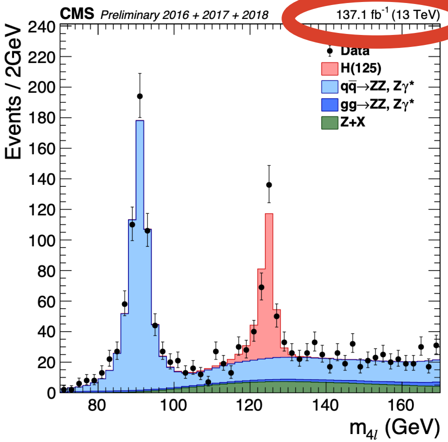




An illustration of results in the past years: H→ZZ



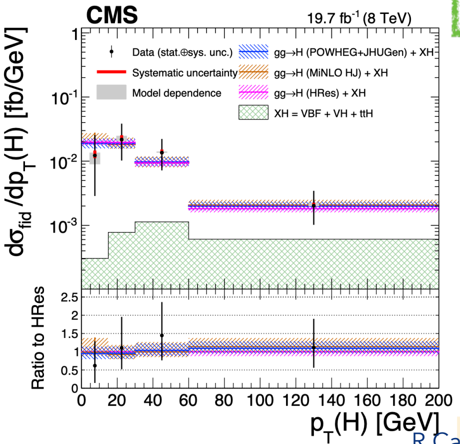




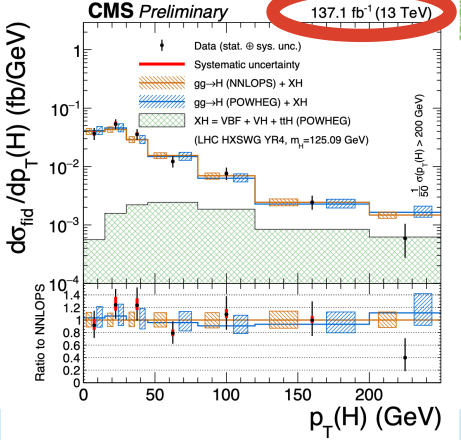
PLB 716(2012)30

Higgs boson observation with Run 1 data in 2012

JHEP 11(2017)47 2016



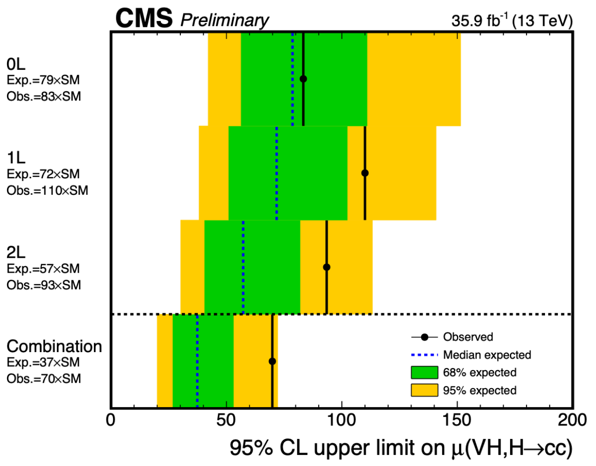
JHEP 04(2016)5 Run 1



HIG-19-001 Run 2

Moving to the 2nd generation fermions

- After having observed the coupling to 3rd generation fermions, now first CMS result on **VH, H→cc**
  - highly challenging due to low cross section and need for c-tagging
    - addressing resolved (2 c jets) and merged (1 cc jet) cases
    - use of ML and jet substructure for tagging and classification



Combined results on signal strength:

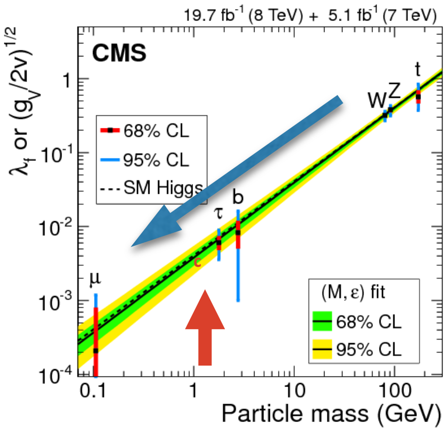
- Obs (exp) exclusion: 70 (37)
- $\mu(\mathrm{VH,H} \to c\bar{c}) = 36^{+20}_{-19}$

Validation using VZ production:

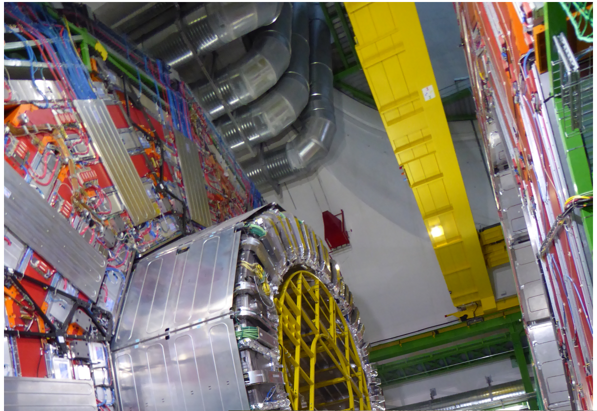
- $\mu(\mathrm{VZ,Z} \to c\bar{c}) = 0.55^{+0.86}_{-0.84}$

For reference: current CMS results on H→$\mu\mu$ signal strength (data from 2016)

- obs (exp) exclusion: 2.92 (2.16)
- obs (exp) significance: 0.9 (1.0) s.d.



Now CMS is in long shutdown 2

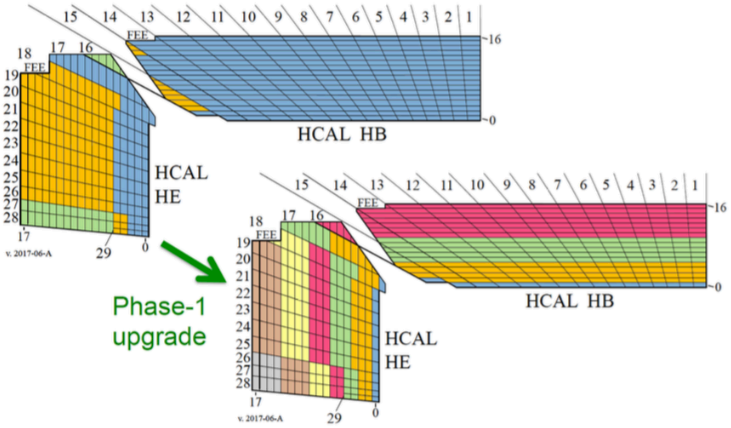


CMS.CERN

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

Again, with strong contributions from JINR

- HB after the conclusion of HE upgrade



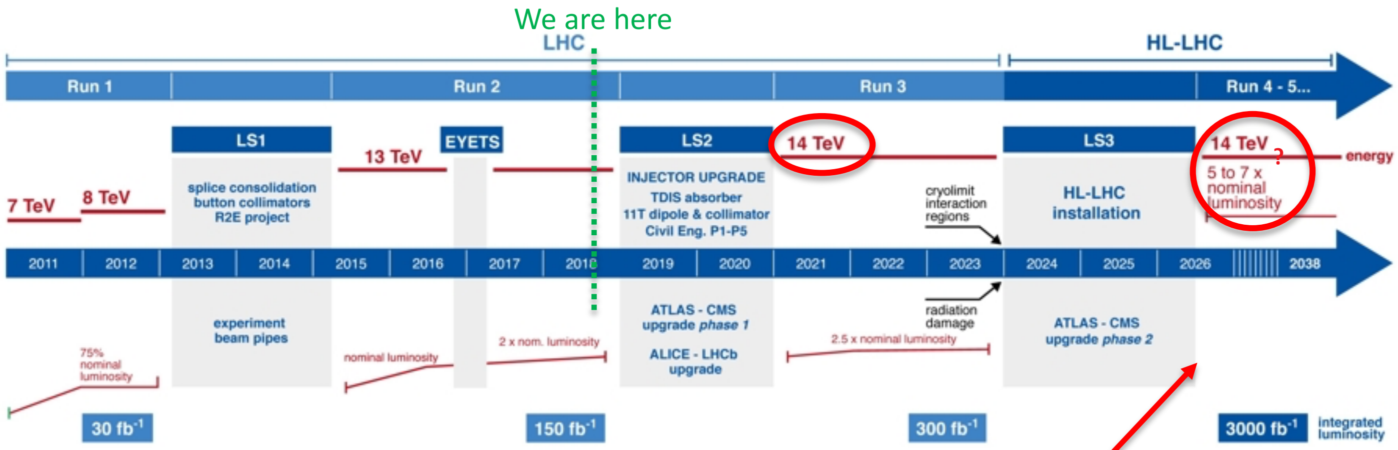
- "Phase 2" CSC electronics upgrade

CSC inner chambers electronics upgrade

HL-LHC

we are planning to run CMS for a long time in the future!

The LHC Luminosity Plan



x5 Run1 x2 Run2 x10 Run3

So far LHC has delivered **5% or less** of the total planned integrated luminosity!

Notice, this is the Nominal Scenario:

L = **5.0**x10e^{34} cm^{-1}s^{-1} up to 3000 fb^{-1} (140 PU)

The Ultimate Scenario forsees:

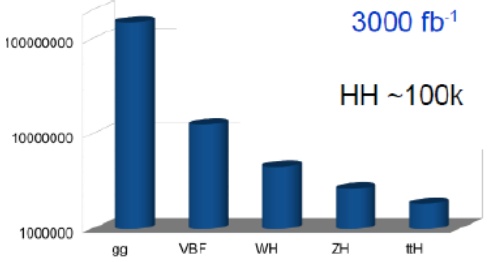
L = **7.5**x10e^{34} cm^{-1}s^{-1} up to 4000 fb^{-1} (200 PU)

Energy might slightly increase between Run 4 and Run 5

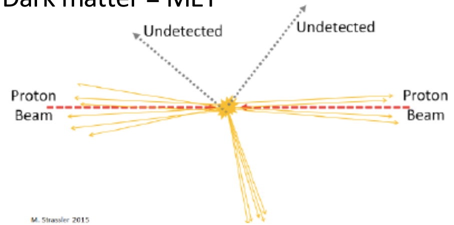
Reasons for HL-LHC

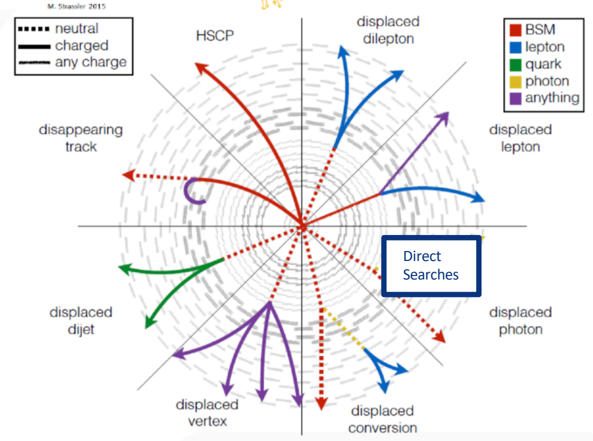
- HL-LHC is a Higgs factory, will produce > 150M Higgs bosons
  - A broad program:
    - Precision O(1-10%) measurements of coupling
    - Exploration of Higgs potential (**HH production with** ~120k of pair produced events)
    - Yukawa to 2nd generation, e.g. **H→ μμ**
  - potential to reveal new particles in loops

- & New Physics – weak scales - low cross-section
  - BSM Higgs searches
  - Long Lived Particles
  - Dark Matter
  - Supersymmetry
  - Extra Dimensions



Dark matter = MET

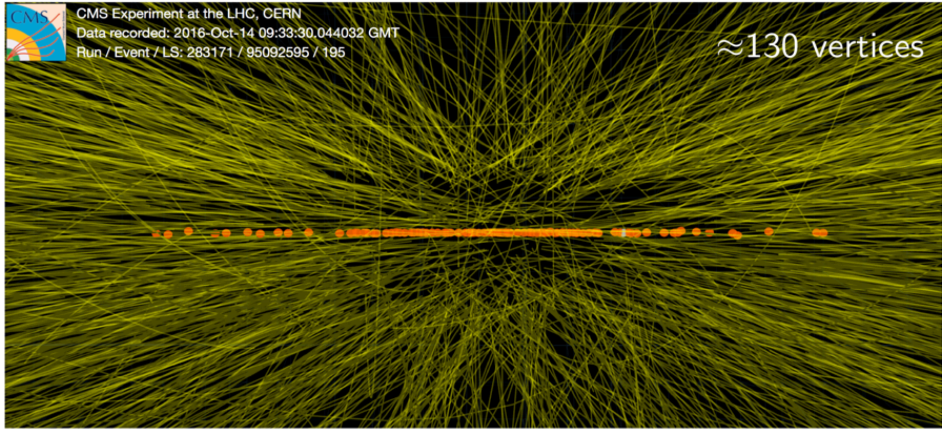


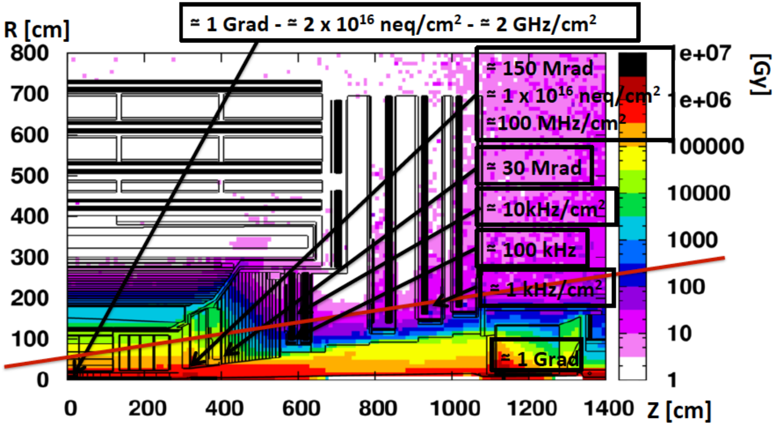


- It's all about high statistics and **better detectors**
  - Need precise & flexible detector and triggers

HL-LHC

- What is the impact on CMS detector: two strong requirements
  - Be able to trigger, readout and analyse data with high instantaneous luminosity and PU up to 140 (200)
  - Be able to cope with a much higher instantaneous and integrated radiation dose





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

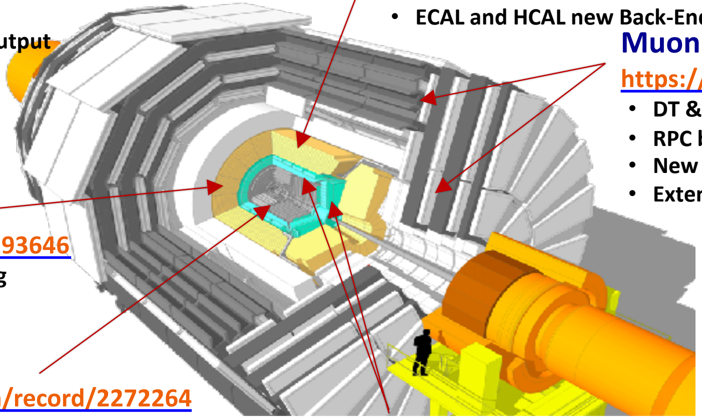
https://cds.cern.ch/record/2283187

- 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 back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$



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 $\eta \simeq 3.8$

MIP Timing Detector

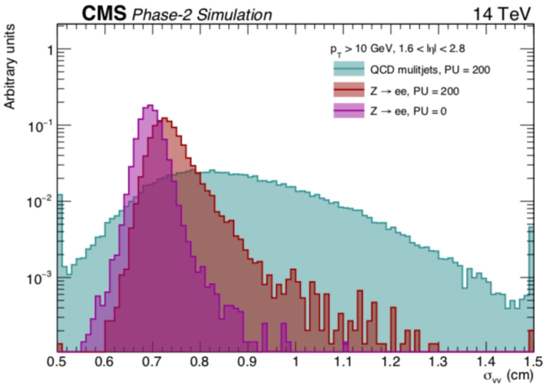
https://cds.cern.ch/record/2296612

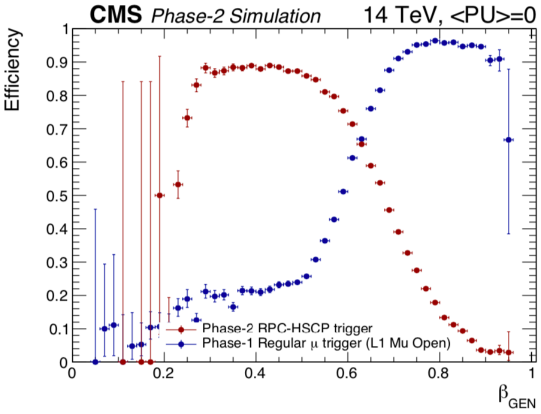
Precision timing with:

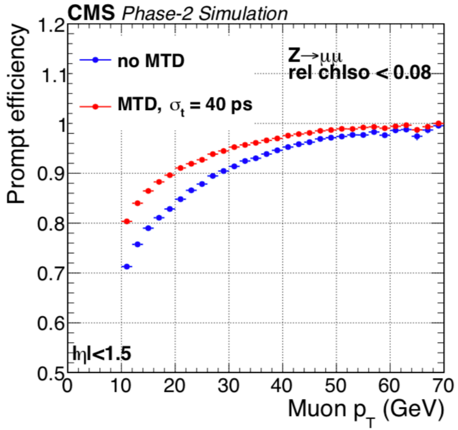
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

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

What are the benefits? Some example







Endcap calorimeters
- fine segmentation provides powerful discriminating variables for e-ID

Muon system
- L1 trigger on delayed signals with upgraded muon readout

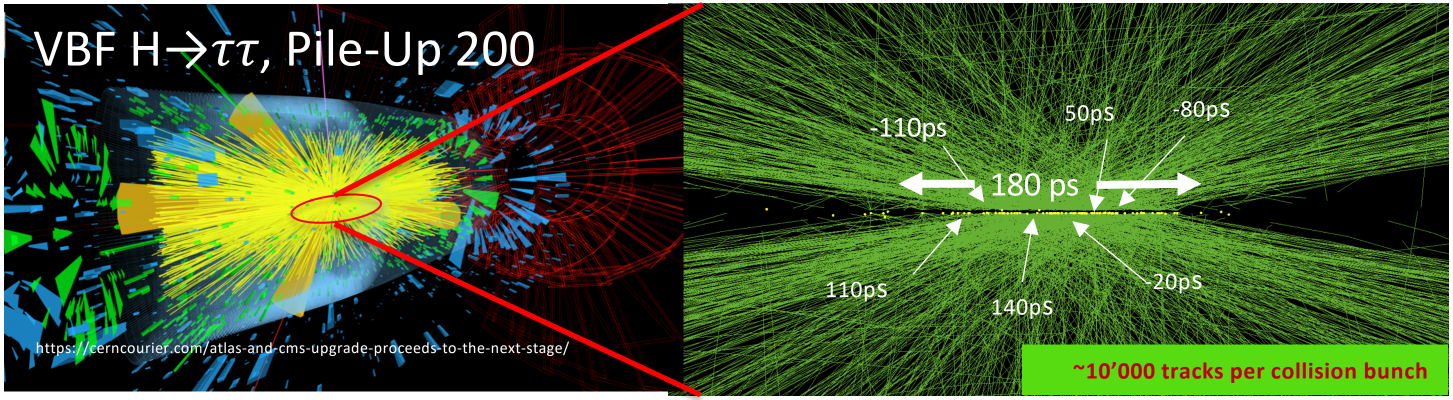
MIP timing detector
- Improved efficiency of the isolation selection for leptons

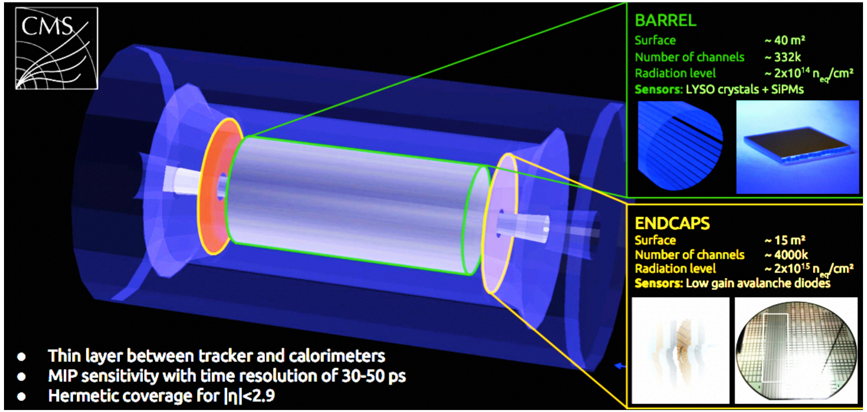
CERN-LHCC-2017-023

CERN-LHCC-2017-012

CERN-LHCC-2019-003

MTD MIP Timing Detector

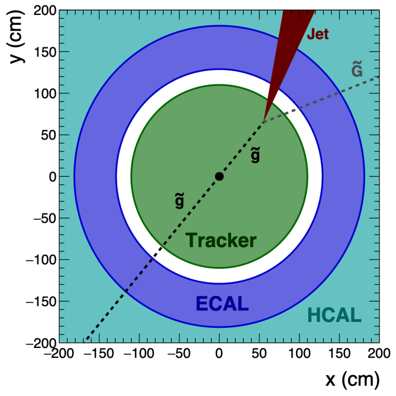




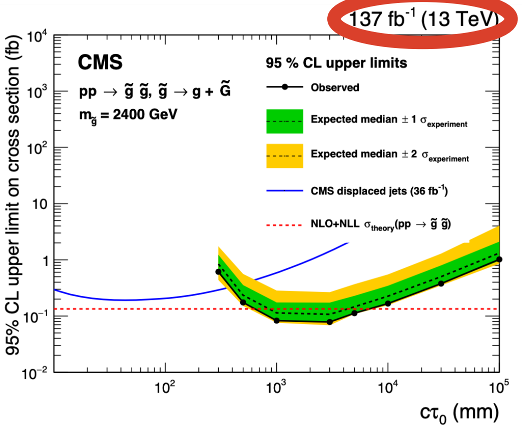
- **30 ps timing – the extra independent parameter makes the difference**
- @ PU=200 Vertex density ~2 vertices/mm
  - Unfold pile-up ⇒ sort 180ps collision area into ’30ps blocks

Delayed jets and Photons

- In HL-LHC CMS is planning to use precision timing information from all calorimeters and MTD, achieving "4 dimensional" reconstruction



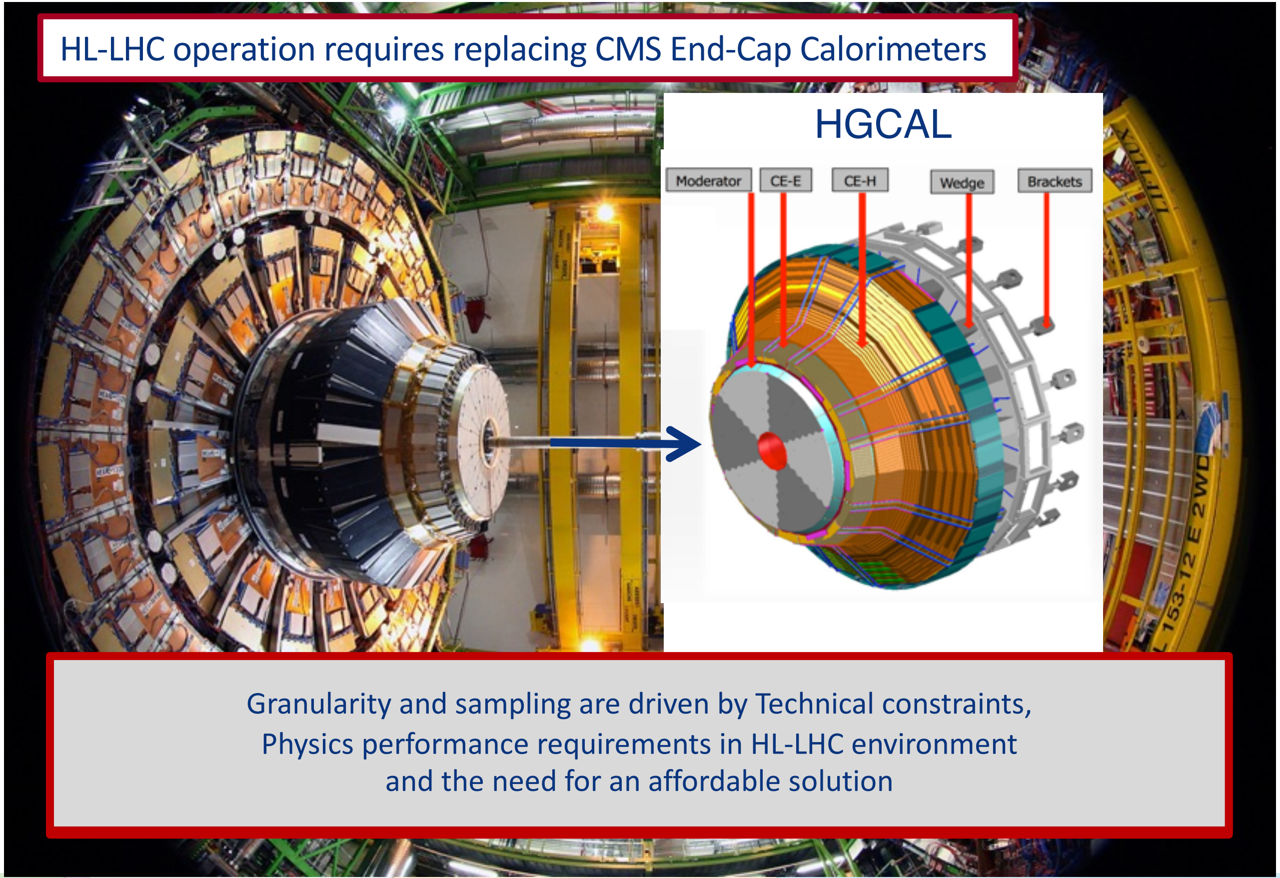
- But we are already using timing now
  - Jet timing using ECAL
    - Long-lived gluinos give rise to jets from displaced vertex
    - Delay due to differences in velocity and in path length
    - uses median time of all ECAL cells in the jet cone
  - Photon timing using ECAL
    - Long-lived neutralinos decay to a photon and a graviton
    - requires precise calibration of ECAL timing and resolution



significant extension of sensitivity w.r.t. delayed jets tracker-based searches

High Granularity Calorimeter (HGCAL)

HL-LHC operation requires replacing CMS End-Cap Calorimeters

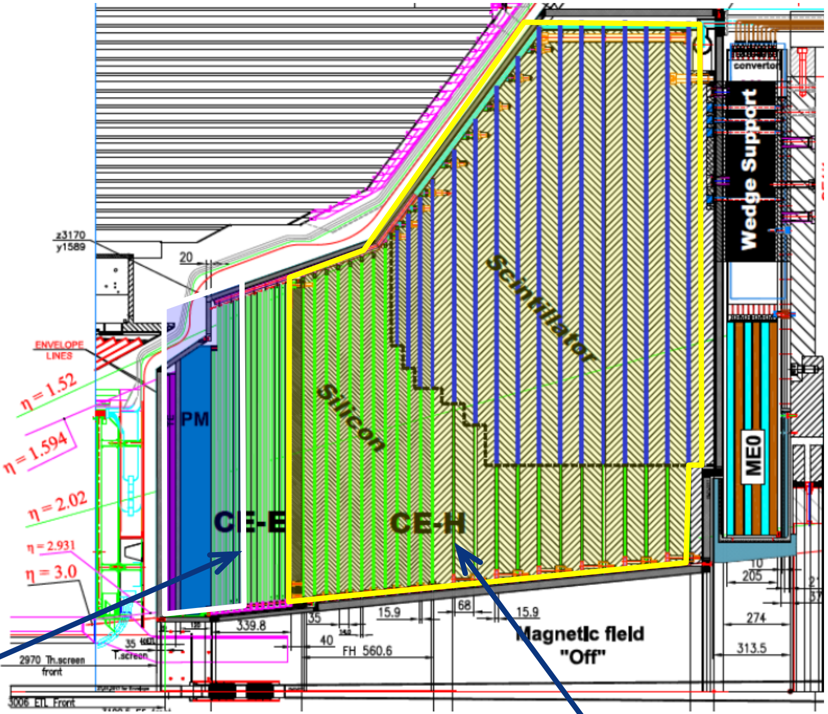


Granularity and sampling are driven by Technical constraints,
Physics performance requirements in HL-LHC environment
and the need for an affordable solution

High Granularity Calorimeter (HGCAL)

New detector features:

- Radiation tolerance (up to 3000 fb^{-1})
- Dense calorimeter (preserving lateral compactness)
- Fine lateral granularity (two shower separation)
- Fine longitudinal granularity (energy resolution, pattern recognition, pile-up mitigation)
- Precise measurement of the time of high energy showers (pile-up rejection, identification of the vertex of triggering interaction)



EM Cal … Less conventional structure
- Pb/SS absorbers are part of cassettes
- Cassettes stacked directly on top of each other

Hadron Cal … Conventional structure
- Steel absorber plates with gaps
- Active detectors (cassettes) inserted into gaps

A Silicon Calorimeter?

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN LIBRARIES, GENEVA

SC00000125

CERN/DRDC/91-54
DRDC/P34
January 13th, 1992

A Silicon Hadron Calorimeter module operated in a strong magnetic field with VLSI read out for LHC

F. Carminati, M. Della Negra, S. Giani, M. Glaser, A. Hervé, J. M. Le Goff, F. Lemeilleur, M. Pimiä, E. Radermacher** and H. Verweij.
CERN, Geneva, Switzerland

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- Silicon Hadron Calorimeter, not a completely new idea
  - Was proposed in '92 by RD35 with Igor as joint Spokesperson!
  - A different (cheaper) solution was chosen with brass/scintillator, but now with the extreme needs from HL-LHC that solution is back
  - And the studies of RD35 also paved the way for the Si-based pre-shower installed in the CMS ECAL endcaps

Conclusions

- CMS is doing very well on operations, present upgrades and data analyses, and it is getting ready for the future, with a challenging and very interesting detector upgrade
- Igor Golutvin, one of the founding fathers of the experiment, has been a strong member of the collaboration, contributing with his team to build and upgrade some of our key detectors and one of the computing Tier 1 centres
- So we owe a lot to Igor, who is an active member of our collaboration, and it is remarkable that we celebrate his jubilee always mentioning the future!