“Shoulder by shoulder with Igor Golutvin: the journey toward the discovery of the Higgs boson”

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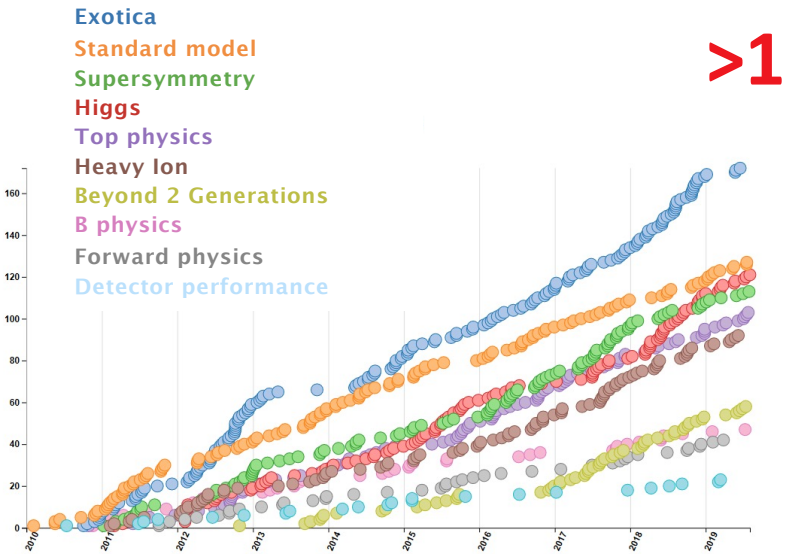
Cern

Seminar in memory of Igor Golutvin

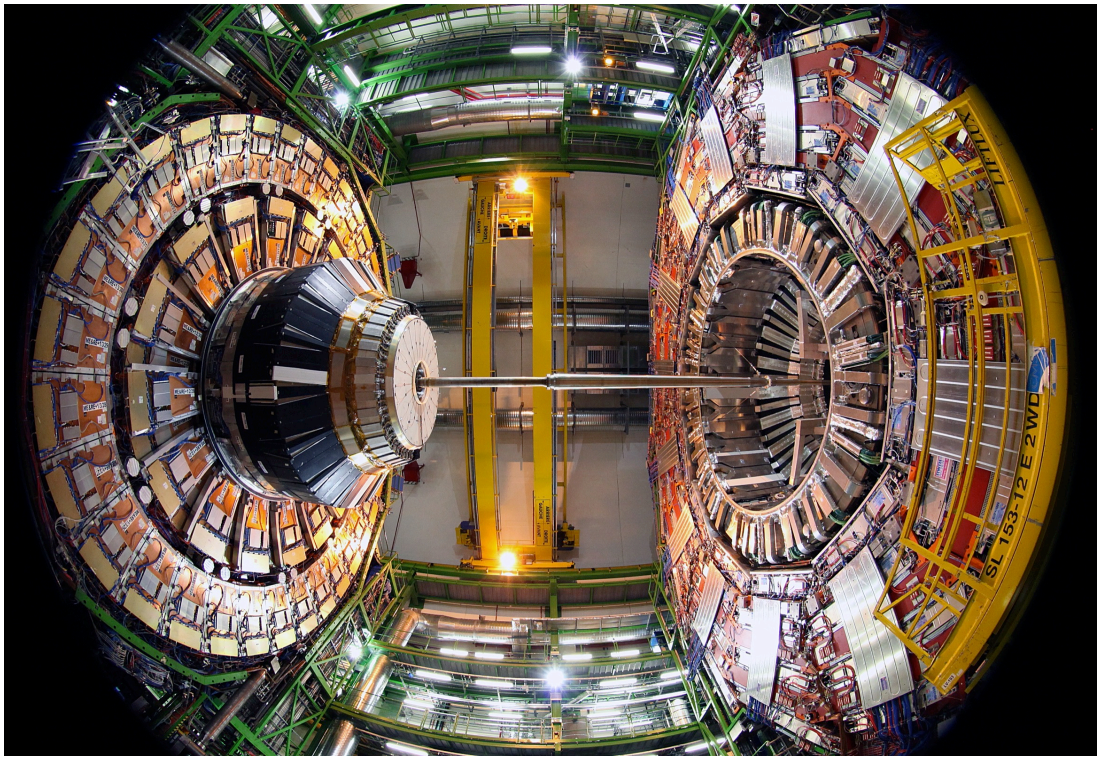
Dubna, 8th August 2024

CMS is an extremely successful experiment.



>1300 physics papers published so far

Thanks to the commitment and ingenuity of thousands of collaborators, and, mostly, **to the magnificent detector we have built together.**



and Igor had a fundamental role in shaping and building CMS.

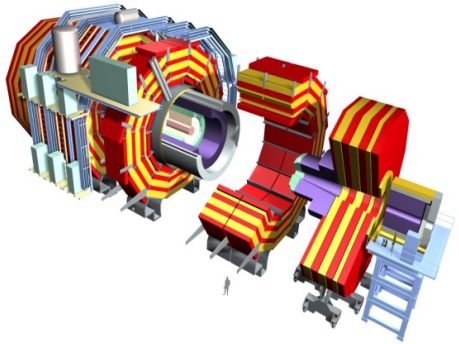
Igor was one of the founding fathers of the CMS collaboration

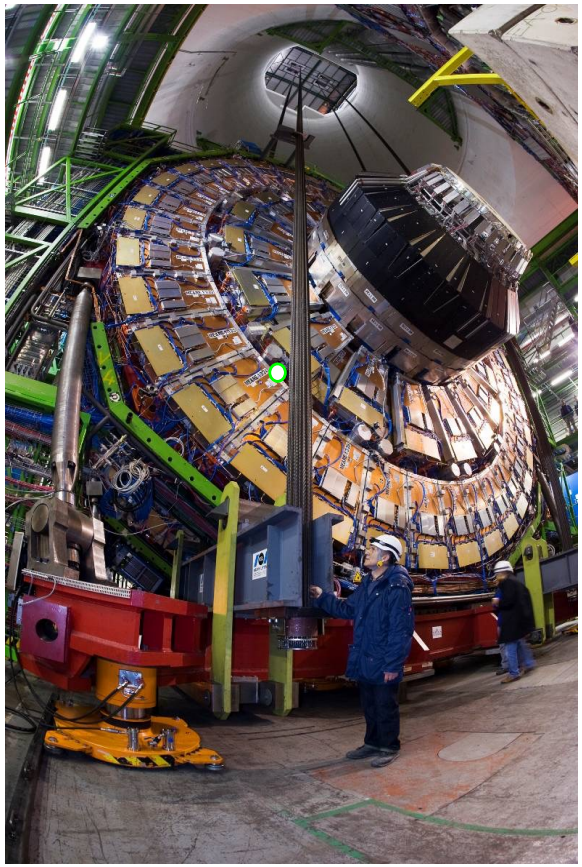
JINR, Dubna, RUSSIA

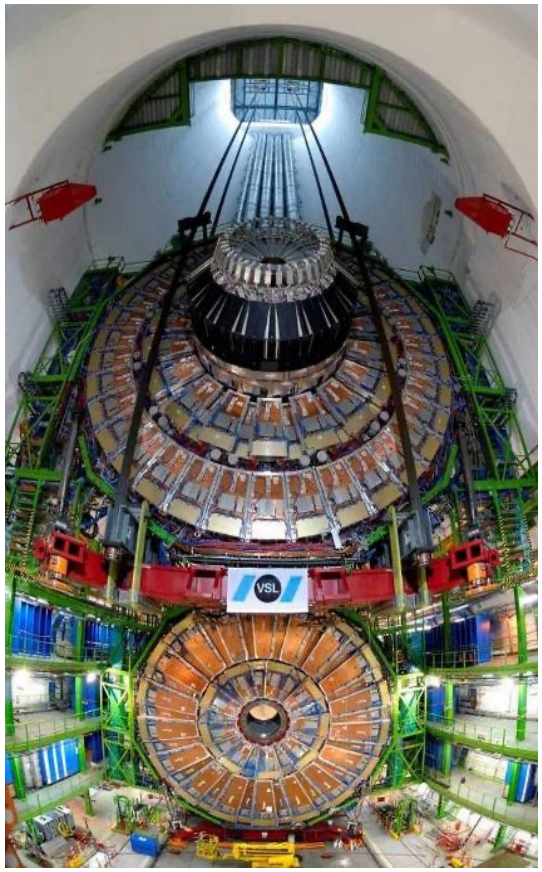
P. Akishin, S. Andreev, A. Bel'kov, M. Bondila, V. Chalyshev, A. Cheremukhin, N. Chernenko, B. Eidelman[6], V. Eremin[7], I. Evsikov, N. Fadeev, A. Feschenko, E. Fefelova, S. Golubykh, I. Golutvin, I. Ivanchenko, L. Ivanjutin[5], V. Ivanov, V. Kalagin, V. Kharlamov[6], A. Khassanov, A. Kotilkov, Z. Kozenkova, 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]

The CMS Endcaps

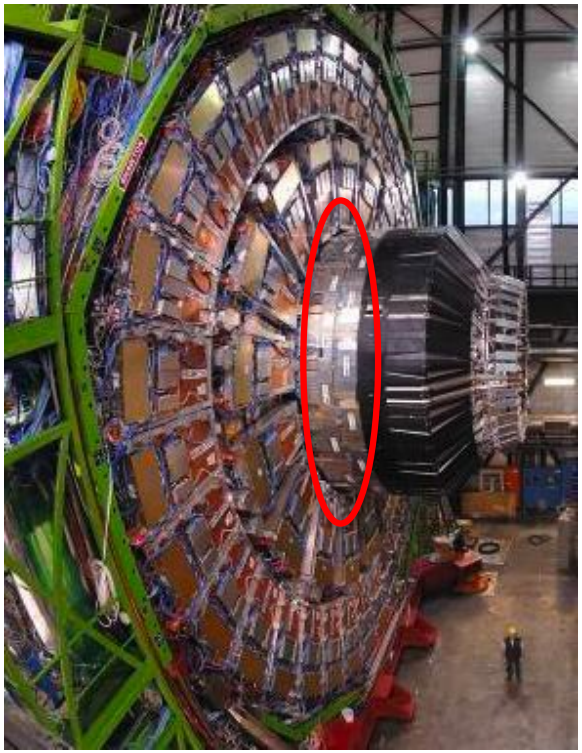
JINR made major contributions to the design, construction, installation and operation of the endcap detectors.



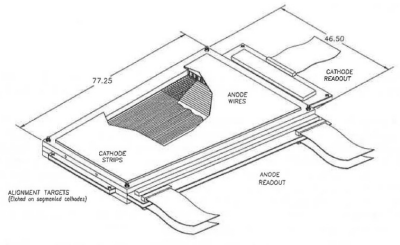




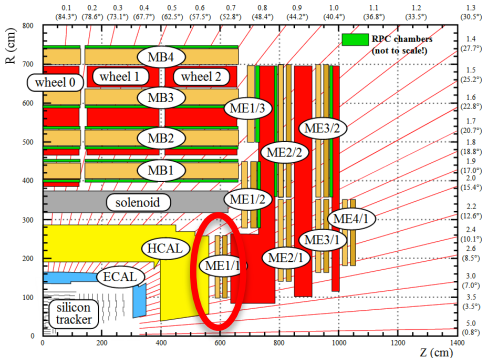
A flagship project: CSC and the ME1/1 muon detector



- CSC are the key muon detector in the endcaps contributing to the readout and trigger in areas of high density of particles.
- **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

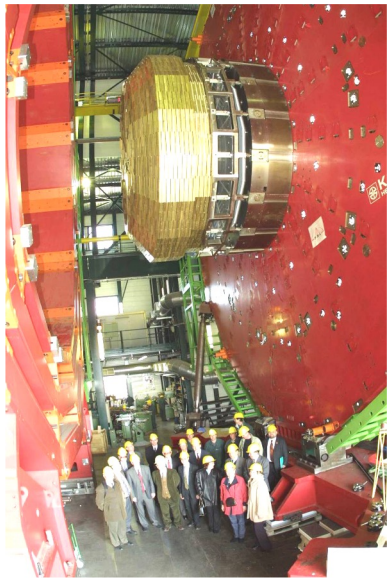


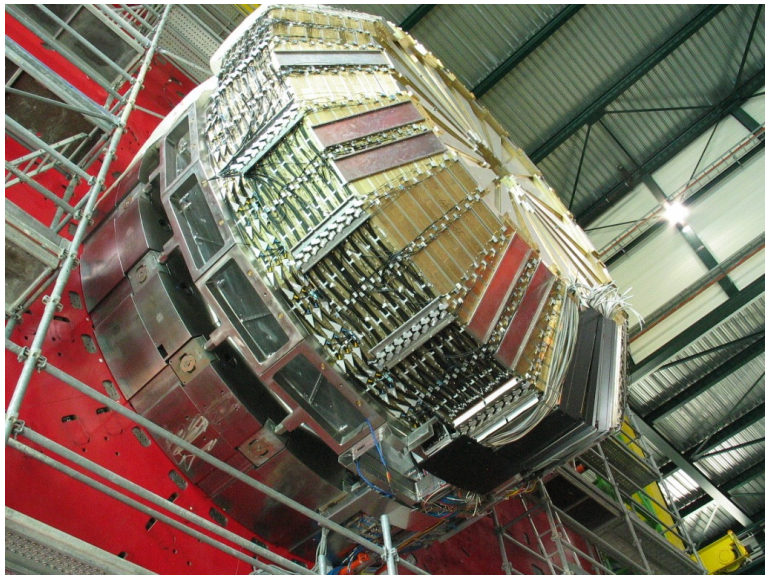
- In particular, ME1/1 were produced in Dubna, with **Igor as ME1/1 project leader**



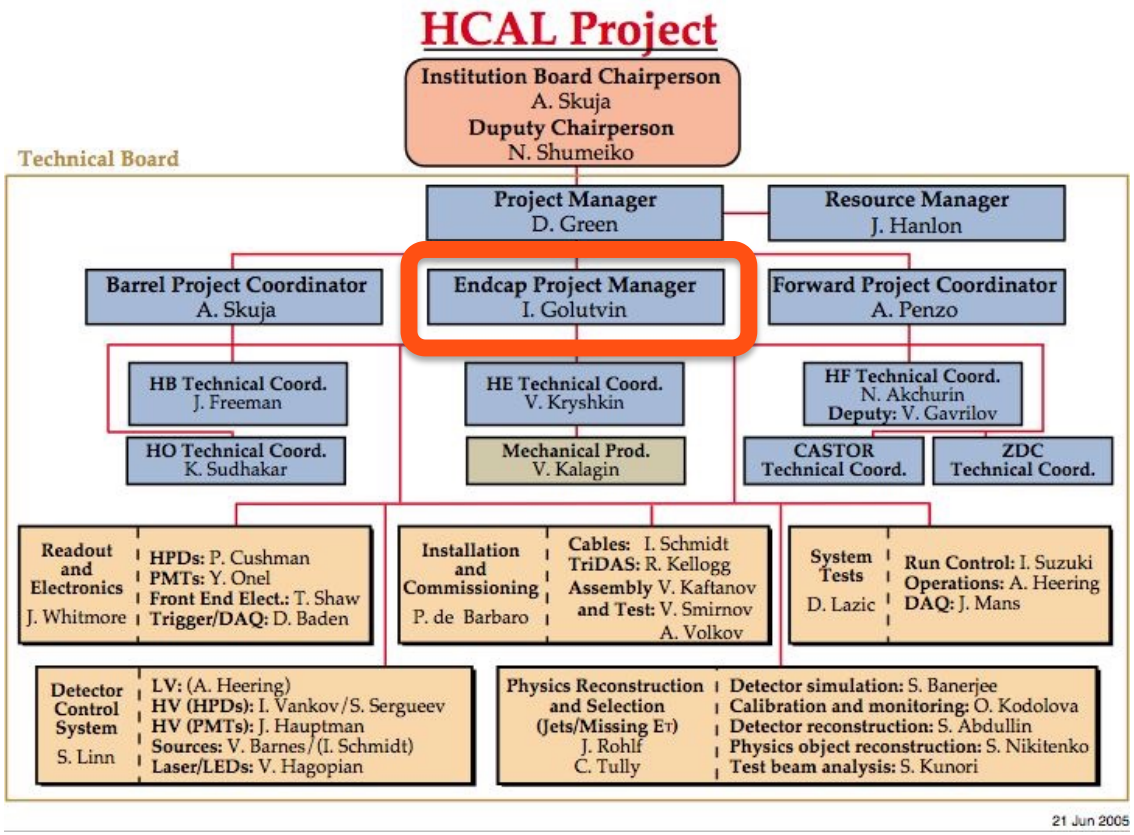
HE, another fundamental part of CMS.

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

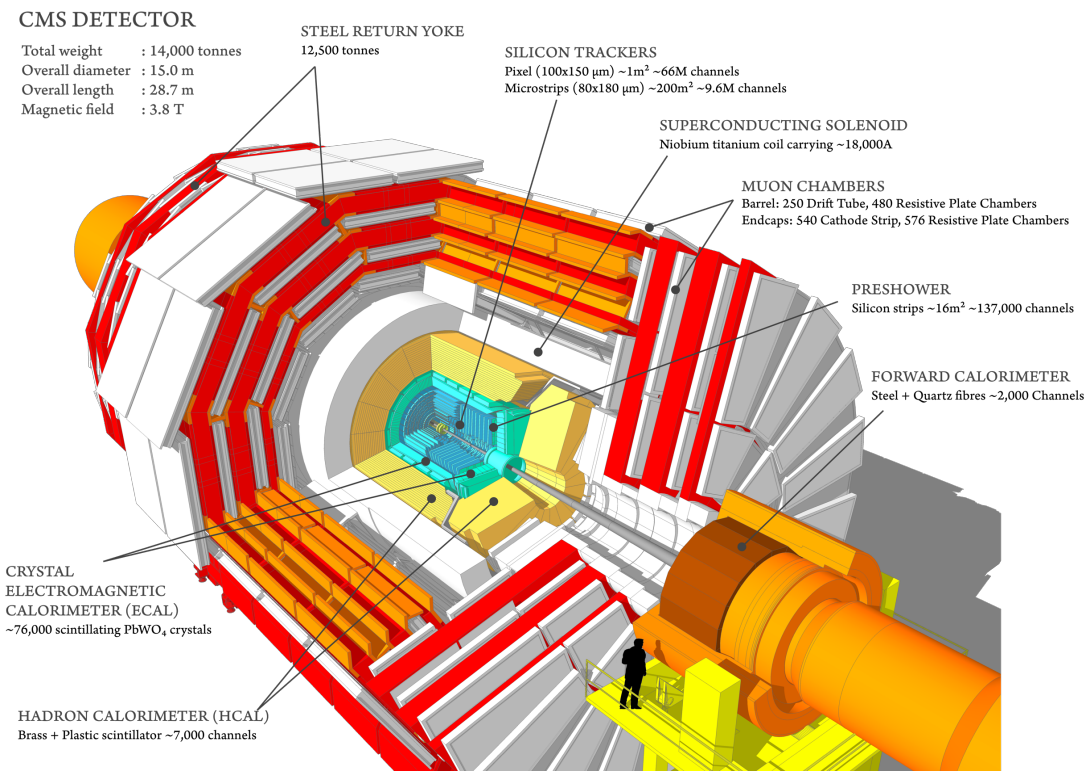




HCAL Org Chart during Installation (2005)



CMS, an evolving, innovative detector



- CMS, an innovative detector from the beginning
  - Large magnet with 3.8T magnetic field.
  - Full Si tracker.
  - 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

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

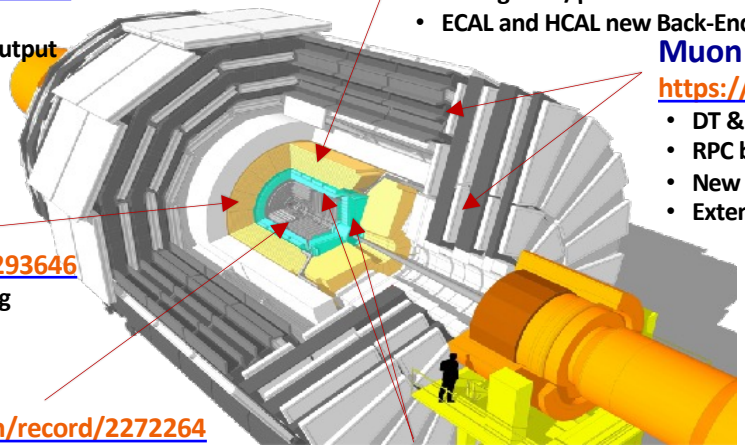
https://cds.cern.ch/record/2283187

- 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

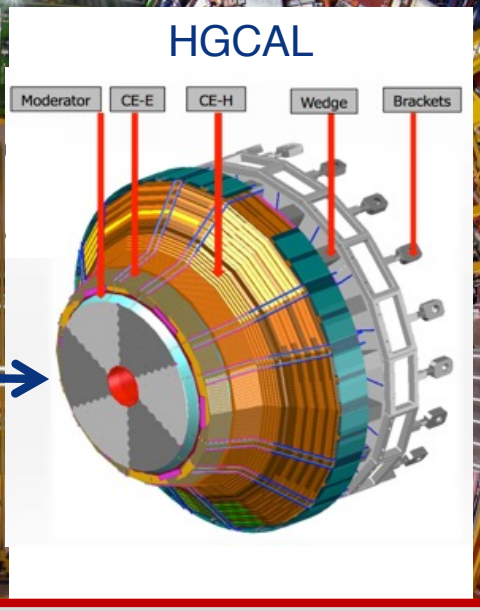
Precision timing with:

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

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

High Granularity Calorimeter (HGCAL)

HL-LHC operation requires replacing CMS End-Cap Calorimeters

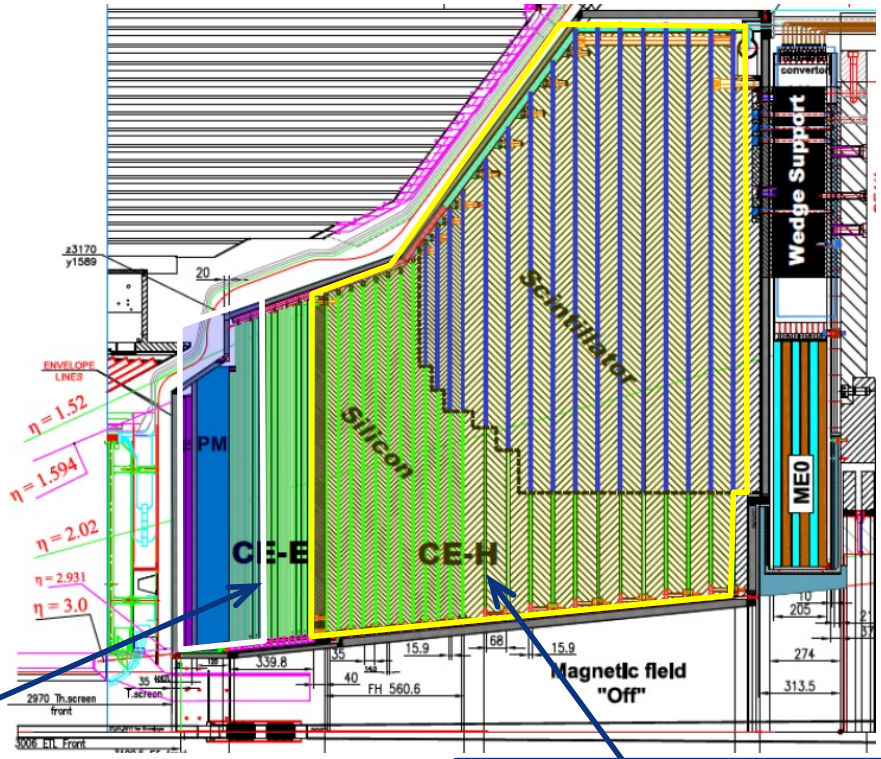


Granularity and sampling are driven by Technical constraints,
Physics performance requirements in HL-LHC environment
and the need for an affordable solution

High Granularity Calorimeter (HGCAL)

New detector features:

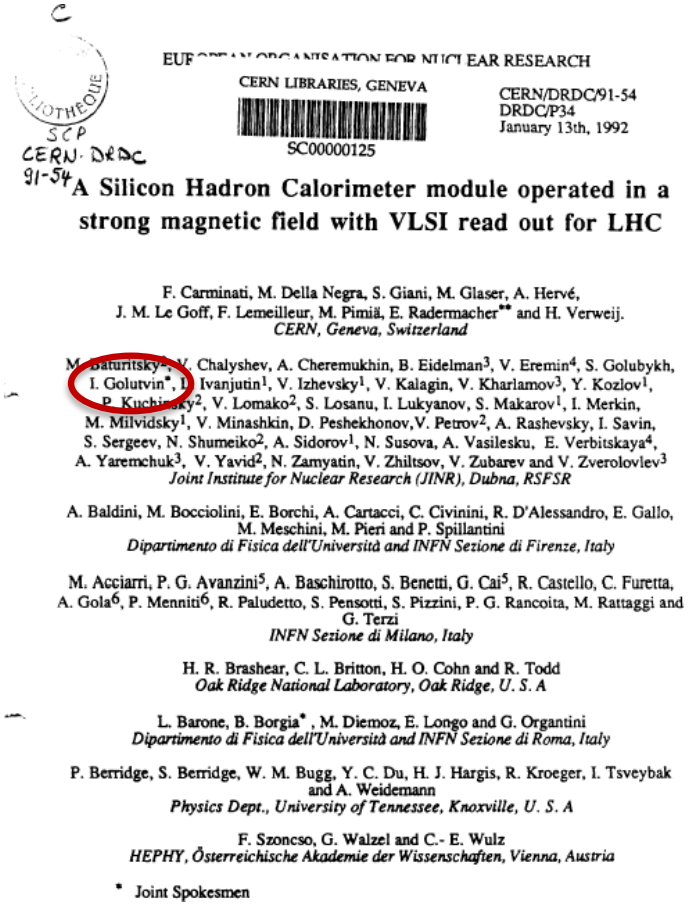
- Radiation tolerance (up to 3000 fb^{-1})
- Dense calorimeter
- Fine lateral granularity
- Fine longitudinal granularity (energy resolution, pattern recognition, pile-up mitigation)
- Precise measurement of the timing of the high energy showers (pile-up rejection, identification of the vertex of triggering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



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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

M. Baturitsky[1], V. Chalyshev, A. Cheremukhin, B. Eidelman[3], V. Eremin[4], S. Golubykh, I. Golutvin*, I. Ivanjutin[1], V. Izhevsky[1], V. Kalagin, V. Kharlamov[3], Y. Kozlov[1], P. Kuchinsky[2], V. Lomako[2], S. Losanu, I. Lukyanov, S. Makarov[1], I. Merkin, M. Milvidsky[1], V. Minashkin, D. Peshekhonov, V. Petrov[2], A. Rashevsky, I. Savin, S. Sergeev, N. Shumeiko[2], A. Sidorov[1], N. Susova, A. Vasilesku, E. Verbitskaya[4], A. Yaremchuk[3], V. Yavid[2], N. Zamyatin, V. Zhiltsov, V. Zubarev and V. Zverolovlev[3]
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M. Acciarri, P. G. Avanzini[5], A. Baschirotto, S. Benetti, G. Cai[5], R. Castello, C. Furetta, A. Gola[6], P. Menniti[6], R. Paludetto, S. Pensotti, S. Pizzini, P. G. Rancoita, M. Rattaggi and G. Terzi
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H. R. Brashear, C. L. Britton, H. O. Cohn and R. Todd
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L. Barone, B. Borgia*, M. Diemoz, E. Longo and G. Organtini
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P. Berridge, S. Berridge, W. M. Bugg, Y. C. Du, H. J. Hargis, R. Kroeger, I. Tsveybak and A. Weidemann
Physics Dept., University of Tennessee, Knoxville, U. S. A

F. Szoncso, G. Walzel and C.- E. Wulz
HEPHY, Österreichische Akademie der Wissenschaften, Vienna, Austria

* Joint Spokesmen

- 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

The role of Igor "behind the scenes"

- All this is well known by the whole scientific community.
- Igor played a leading role in the development of CMS, one of the most successful experiment ever.
- What is less known is the role of Igor "behind the scenes". In particular during the hunt for the Higgs boson and Igor's crucial contribution to the success of the experiment in the most important discovery of this century.
- This is what I would like to remember here.

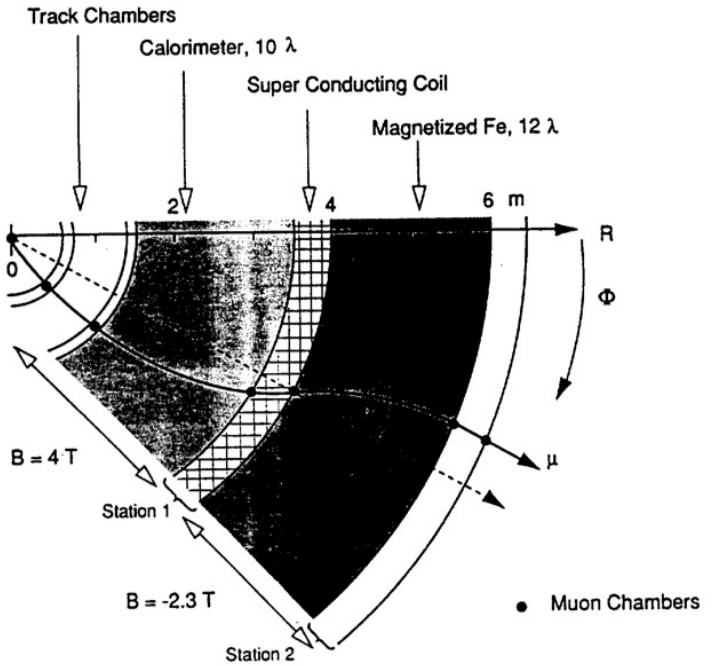
1990 Aachen Workshop

Compact Muon Solenoid

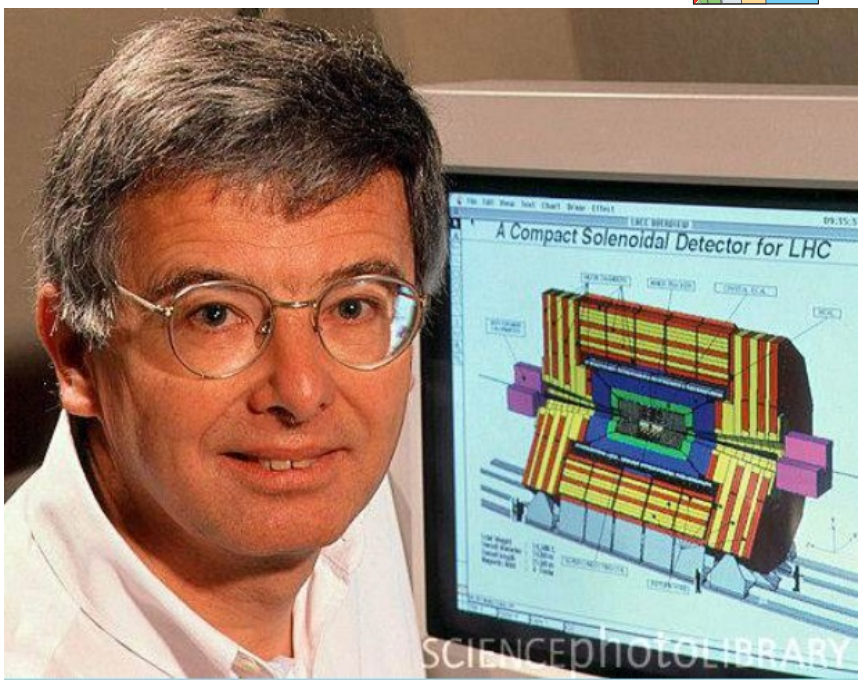
M. Della Negra, K. Eggert, M. Lanzagorta, M. Pimiä, F. Szoncso

presented by M. Pimiä

SEFT, University of Helsinki, Finland



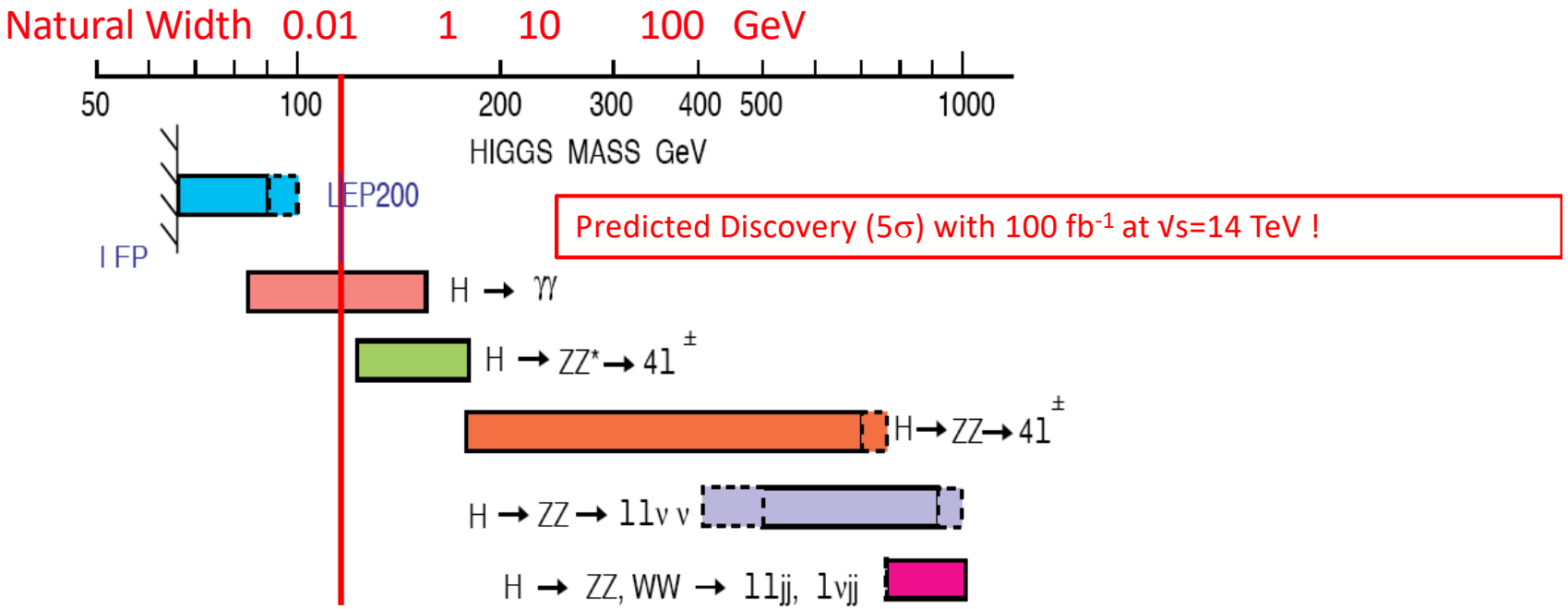
Aachen: Tower of St. Foillen and the Cathedral



Michel della Negra, founder of the experiment and first Spokesperson of CMS (1992-2006).

The discovery of the Higgs boson was set as the major goal of the experiment since the very beginning.

Search for the SM Higgs Boson with CMS (1994)

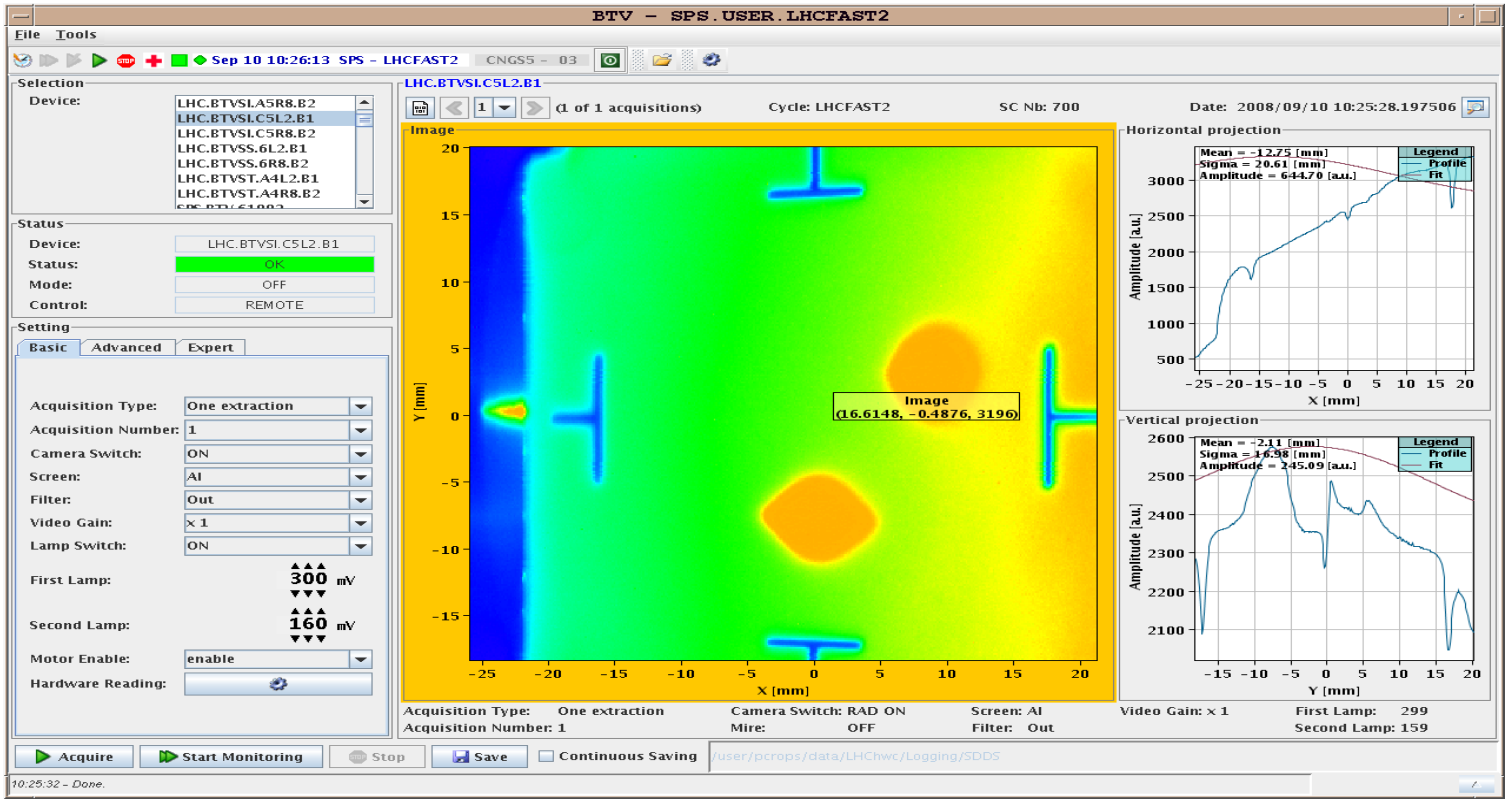


Search for a low mass Higgs boson (e.g. H→γγ, H→ZZ→4l) placed stringent performance requirements on the tracker momentum and ECAL energy resolution.

It took 15 years of incredible efforts to build CMS

10/09/2008: first beam in LHC

- 2 shots of clockwise beam: 2×10^9 protons per beam



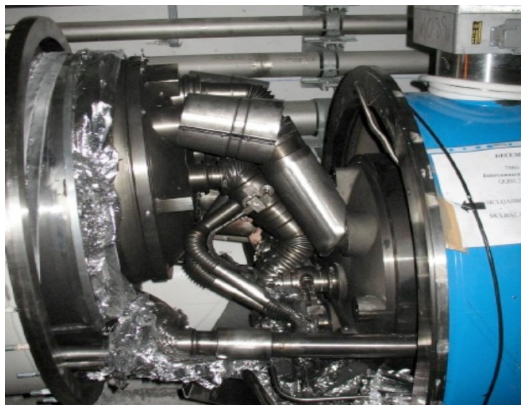
A lot of excitement in all control rooms

9 days later 19/09/2008: our black friday

A defective interconnection between two magnets produced a serious incident during a powering test of one LHC sector.

A massive helium loss in one arc of the machine caused important mechanical damage to tens of dipoles and quadrupoles.

~1 year of work to replace/repair/re-check 53 magnets and to put in place any sort of test and all possible preventive actions to avoid the same incident could happen again.

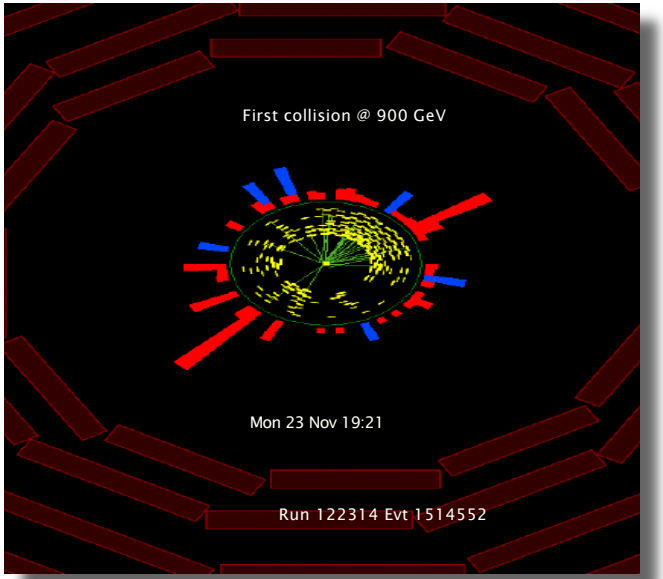


The new LHC Start-Up in 2009

- Nov.20: Start of 2009 beam circulation
- Nov. 23: First collisions at 900 GeV
- Nov. 26: First physics results shown in public at CERN!
- Dec.6: First physics fills
- Dec.8: Acceleration
  - both beams ramped to 1.18 TeV each
- Dec.11: Higher proton intensities (7E10)
  - Starting to accumulate luminosity at 900 GeV
- Dec.14, Collisions at 2.36 TeV !

- **March 30 2010 First Collisions at 7TeV**

First CMS Collision Event



New plan for the LHC

- **2010: first physics run, 7TeV, $L>2x10^{32}cm^{-2}s^{-1}$, ($40pb^{-1}$ delivered)**
- **2011: 7TeV, $L>1x10^{33}cm^{-2}s^{-1}$ ($>1fb^{-1}$ delivered)**
- **2012: 7TeV , $L> 1x10^{33}cm^{-2}s^{-1}$($>3fb^{-1}$ delivered)**

ELECTROWEAK AND TOP PHYSICS
SUPERSYMMETRY AND SEARCHES

NO HOPE TO DISCOVER SOON THE HIGGS BOSON

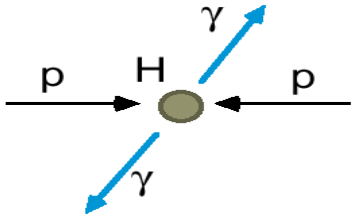
- 2013-14: long shutdown to completely repair all the splices interconnecting the magnets and prepare the machine for 14 TeV.
- 2014-2015-2016: LHC at **13-14TeV** and **$L> 10^{34}cm^{-2}s^{-1}$**

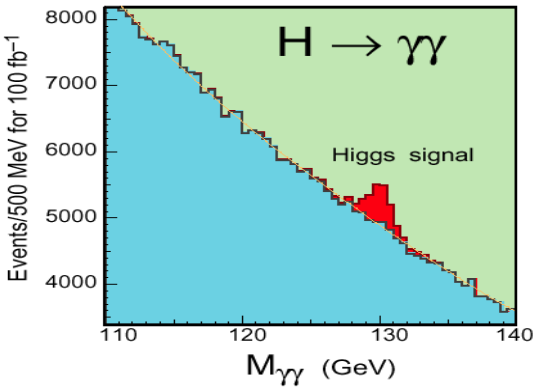
Here we had the first reaction.

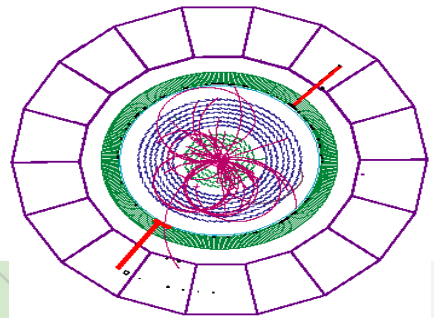
- At that time I was Spokesperson of CMS.
- Igor was among the strongest supporters for my election.
- We had many exchanges of ideas on the main challenges of the experiment and we discussed regularly the main strategic decisions.
- He was a sort of special advisor and I consulted him every time I had to make difficult choices.
- Summer 2010 was one of those difficult moments. At that time, with a small bunch of people, I started studying a very aggressive option.
- **Change completely the strategy to hunt for the Higgs boson and try to discover it with LHC running at 7TeV. Igor was one of the few immediately supporting the idea and helping me to implement it.**

The old strategy

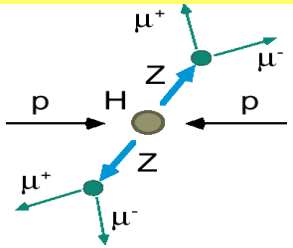
Low $M_H < 140$ GeV/c^2

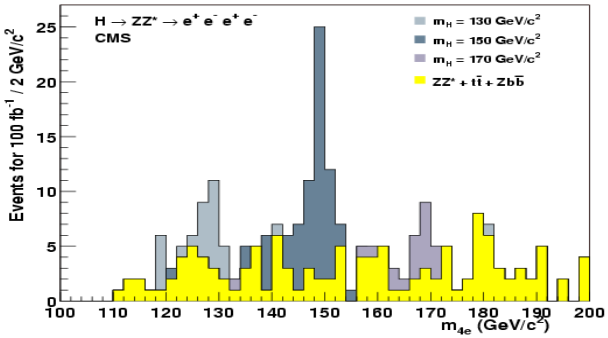


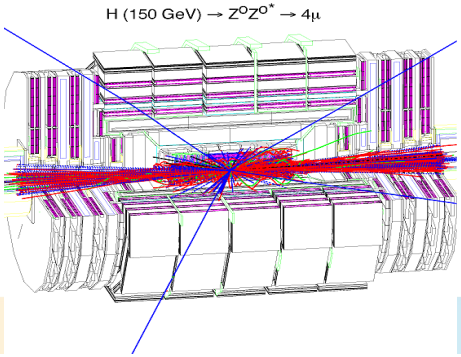




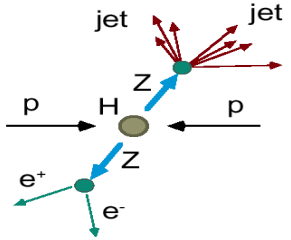
Medium $130 < M_H < 500$ GeV/c^2

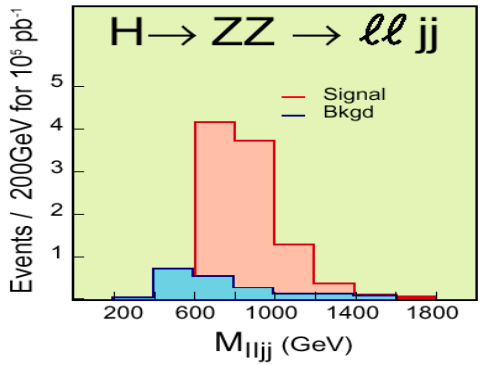


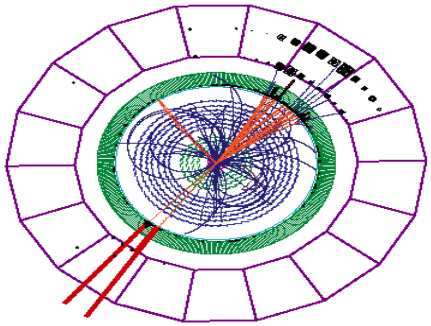




High $M_H > \sim 500$ GeV/c^2

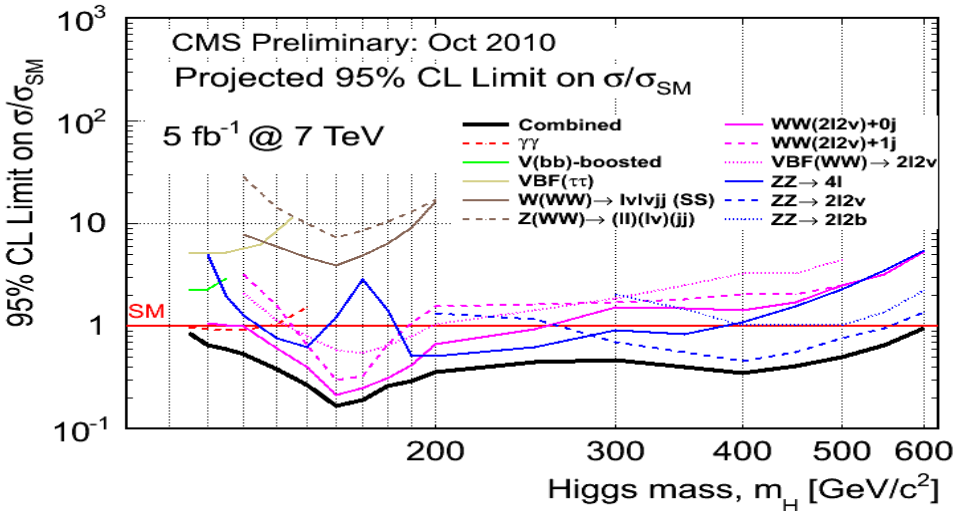




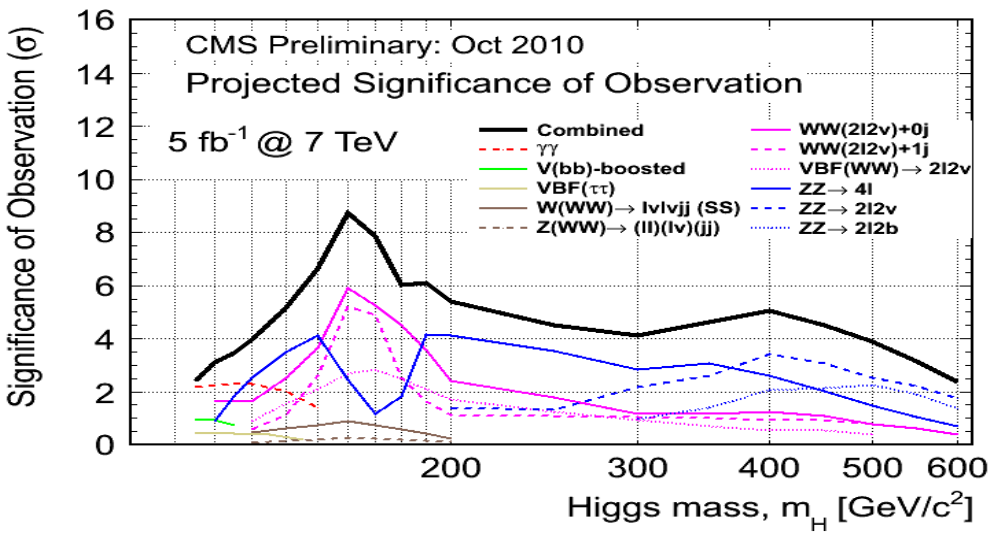


The new strategy

CMS Projected Sensitivity @5fb^{-1}



CMS Projected Significance @5fb^{-1}



October 2010: with 5fb^{-1} delivered by LHC we could reach a sensitivity below 1xSM in the full mass range.

If the SM Higgs boson would be hidden in the low mass region we could start seeing excesses with a significance of 2-3 sigma.

Every single channel, particularly in the low mass region, brings very important information.

Goal: discover the Higgs at 7 TeV !

This was the "mission impossible" was set up in July 2010.

"We'll discover the SM higgs boson-or exclude it forever- before entering the long shut-down needed to run LHC at 14TeV"

After the terrible incident of LHC and the decision **to run at 7 TeV** in 2010 nobody really believed that we could have seriously addressed the discovery of the Higgs boson before the repair of the splices of LHC to **run at 13-14TeV**.

If we are here today it is just because an incredible effort has been put together basically from scratch.

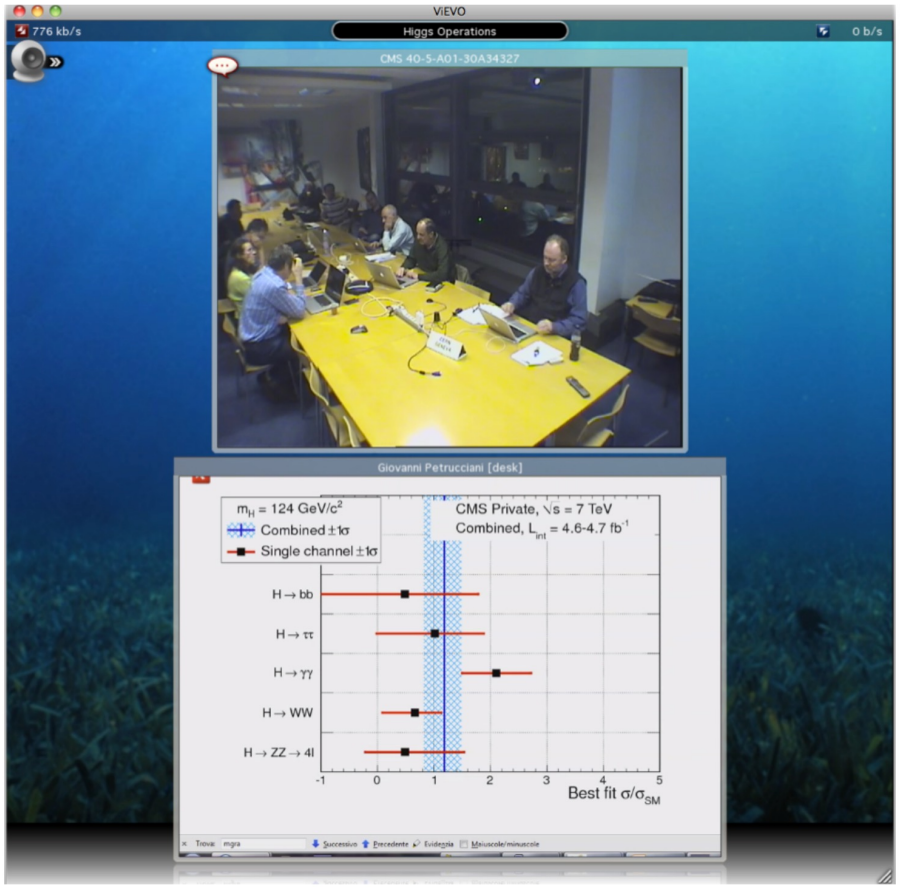
New ideas, completely new approaches, very aggressive and modern analysis tools.

MAJOR ROLE IN THE NEW STRATEGY TO DISCOVER THE HIGGS BOSON PLAYED BY STUDENTS AND POST-DOCS.

Another key moment.

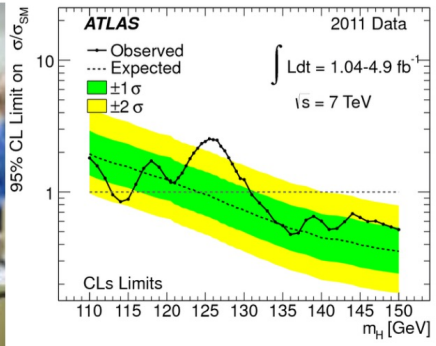
- At the end of 2011 LHC delivered us $5fb^{-1}$ of data and we started seeing interesting events and small excesses around 125GeV.
- Nothing dramatic, but 2-3 sigma effects were appearing summing up the most sensitive channels.
- We had to decide what to do.
- The collaboration was split. We had very heated discussions. Many experienced physicists were afraid of showing in public these results.
- Some argued that everything was fake and we were only showing background fluctuations. Many excellent scientists bet against the presence of the Higgs boson at 125GeV.
- **Igor stood always by me, supporting with energy the decision to show in public what, today we know it, was the first evidence of the Higgs boson at LHC.**

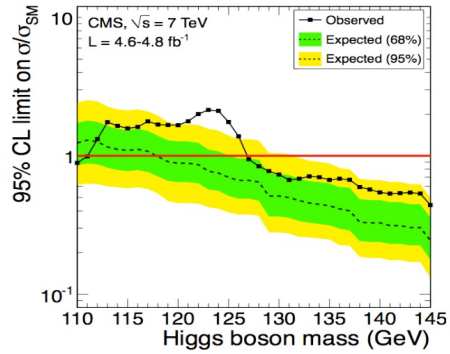
Hectic moments. Dec 10 2011 19:08:56



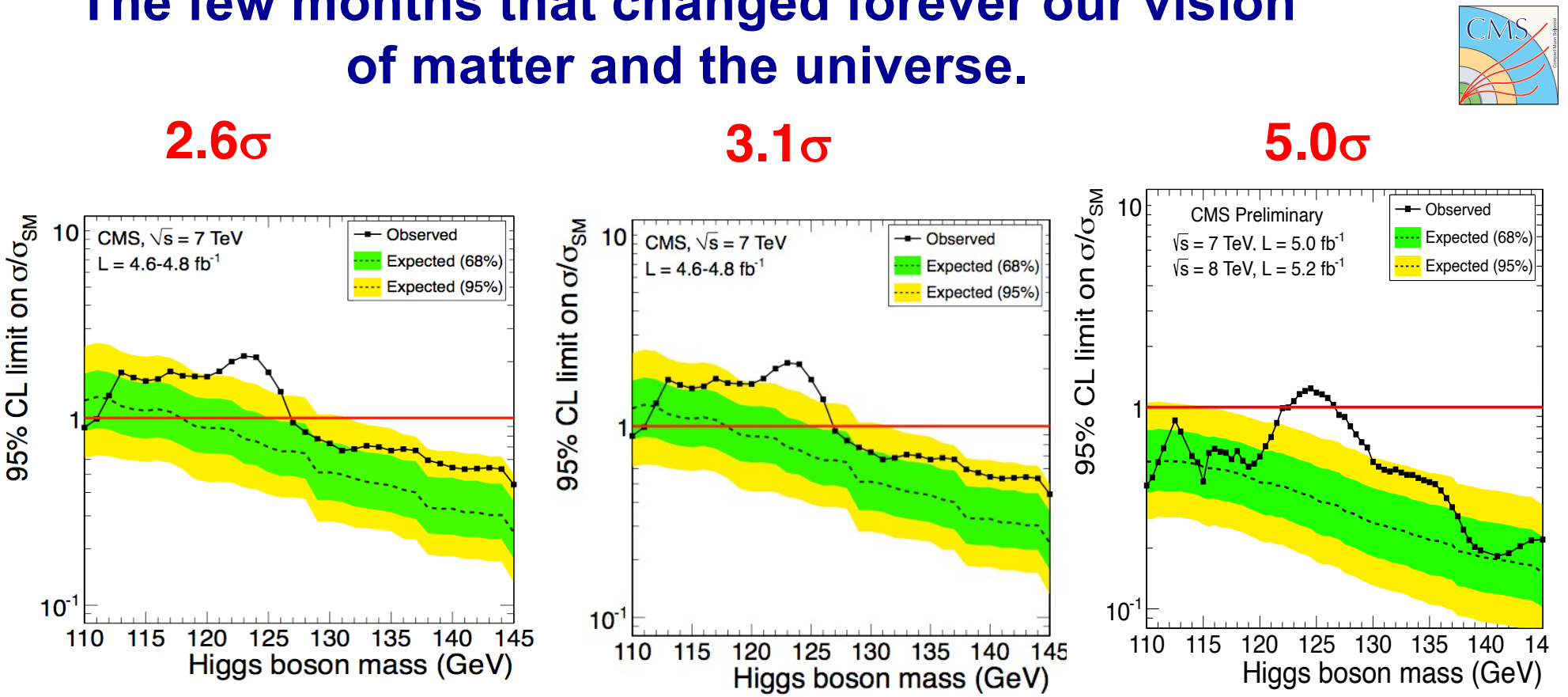
December 13th 2011: the moment of truth!

First evidence of an excess around 125 GeV





The few months that changed forever our vision of matter and the universe.

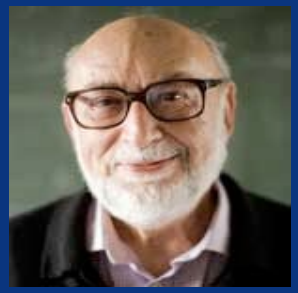


13 Dec 2011 1st seminar.

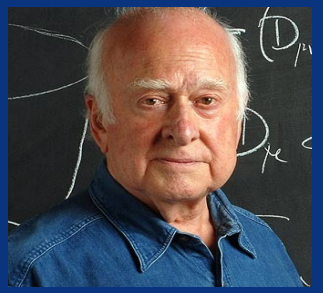
7 Feb 2012 paper

4 Jul 2012 2nd seminar

Nobel Prize for Physics 2013



Francois Englert



Peter Higgs

jointly assigned to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider "*

Conclusions

- Igor Golutvin was not only a great scientist.
- He was a real "maestro" for entire generations of young scientists.
- I feel as a real privilege to have worked with him, sharing some of the most exciting moments of my entire professional life.
- The entire world of High Energy Physics owes a lot to Igor Golutvin but he was also one of my best friends.
- I miss him immensely.
- Thanks to Anatoli, Victor, Andrei and to the many friends attending this seminar for having organized it.