PAST, PRESENT, FUTURE
of the
CMS/INPP group

Georgios Daskalakis
on behalf of the CMS/INPP group

Ag. Paraskevi, 21 Nov 2019
International Scientific Advisory Committee Meeting

the "Big Bang" of INPP High Energy group

… some highlights …

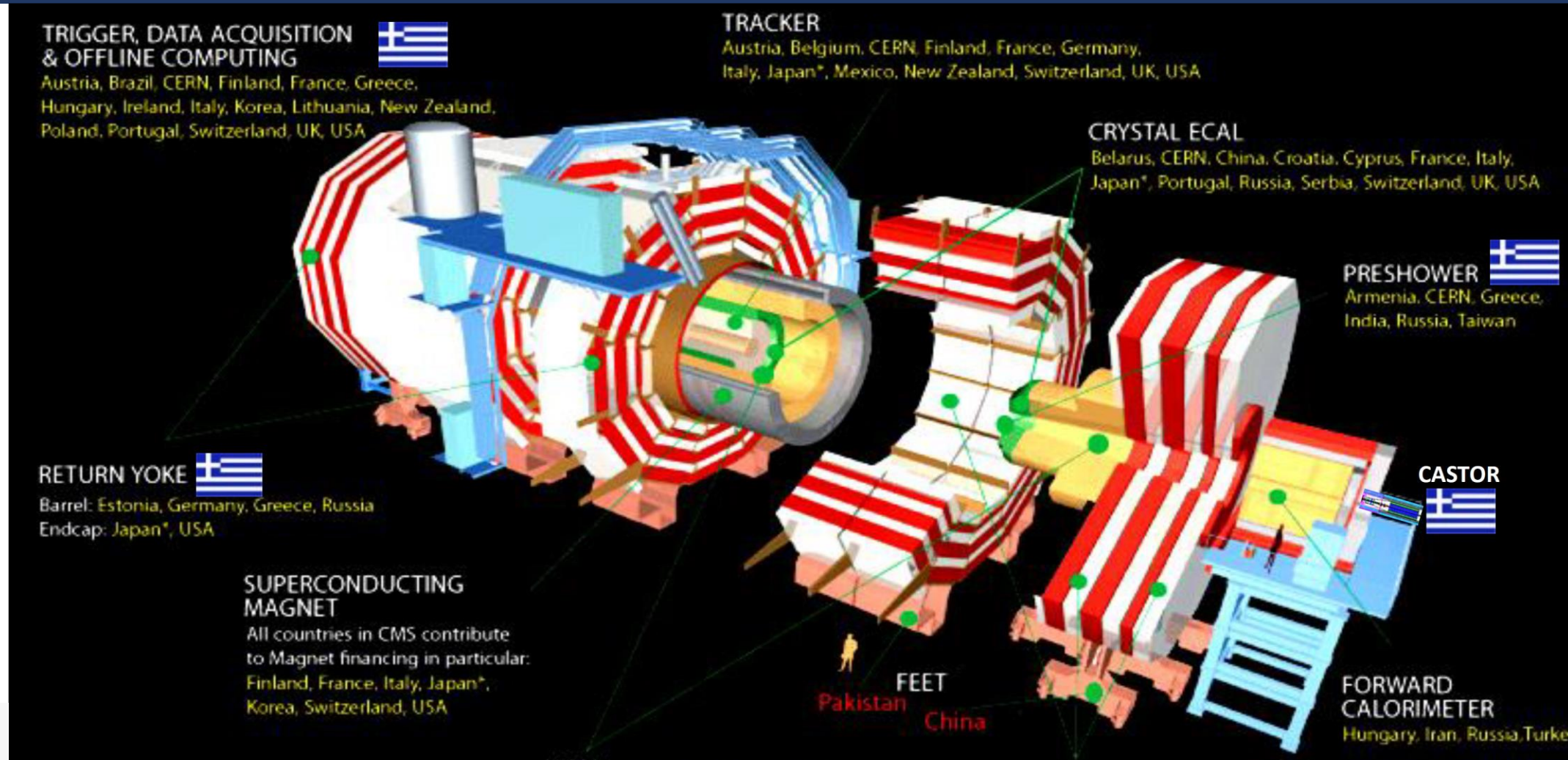
1962 : E.Simopoulou (Cornell). Builds prototype **Spark Chamber.**
1965 : Tom Ypsilantis arrives. Among the pioneers for the *antiproton discovery (1955).*
Participation in **Bubble Chamber** experiment at CERN
1963 – 1979: Anna Vayaki Neutrino physics (BEBC, BNL)
1985 – 1987: CPLEAR/CERN

1980 Starts the LEP/CERN collider activity : **ALEPH & DELPHI** experiments

1980 : Manolis Dris initiates **instrumentation** with "electronic" detectors
1984 – 1989 : Participation in the construction of the **ALEPH** Time Projection Chamber (TPC, **A. Vayaki**)
1984 – 1993 : Construction of the **DELPHI** Ring Imaging CHerenkov detector (RICH) **(T. Ypsilantis)**
Construction of the Barrel RICH Drift Field frames (**G. Theodosiou**)
RICH Calibration system (**A. Markou**)
Until 2002 : Physics measurements in **ALEPH & DELPHI experiments** using **LEP I** and **LEP II** data

1995 : Group joins the CMS collaboration at the LHC

CMS GREECE



TRIGGER, DATA ACQUISITION & OFFLINE COMPUTING
Austria, Brazil, CERN, Finland, France, Greece, Hungary, Ireland, Italy, Korea, Lithuania, New Zealand, Poland, Portugal, Switzerland, UK, USA

TRACKER
Austria, Belgium, CERN, Finland, France, Germany, Italy, Japan*, Mexico, New Zealand, Switzerland, UK, USA

CRYSTAL ECAL
Belarus, CERN, China, Croatia, Cyprus, France, Italy, Japan*, Portugal, Russia, Serbia, Switzerland, UK, USA

PRESHOWER
Armenia, CERN, Greece, India, Russia, Taiwan

CASTOR

RETURN YOKE
Barrel: Estonia, Germany, Greece, Russia
Endcap: Japan*, USA

SUPERCONDUCTING MAGNET
All countries in CMS contribute to Magnet financing in particular: Finland, France, Italy, Japan*, Korea, Switzerland, USA

FEET
Pakistan
China

FORWARD CALORIMETER
Hungary, Iran, Russia, Turkey, USA

HCAL
Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Georgia, Russia, Ukraine, Uzbekistan
HO: India

MUON CHAMBERS
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain
Endcap: Belarus, Bulgaria, China, Colombia, Korea, Pakistan, Russia, USA

* Only through industrial contracts

Total weight	: 12500 T
Overall diameter	: 15.0 m
Overall length	: 21.5 m
Magnetic field	: 4 Tesla

Overview of CMS/INPP activities

Hardware Commitments

1) The ECAL Preshower project (ended 2010)
2) Trigger & DAQ project, (TriDas; ended 2010)
3) Tracker Phase-2 Upgrade project (ongoing, expected end 2025)

Physics Analysis preparation (2005 – 2009)

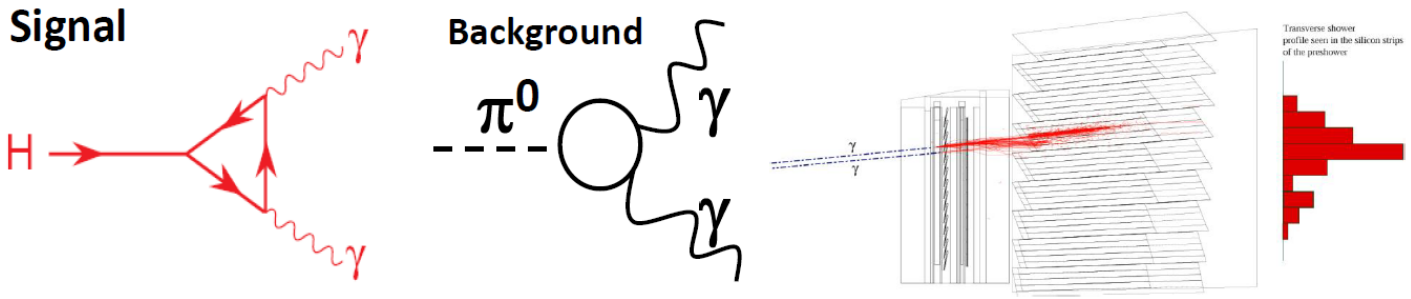
Physics Studies and simulation

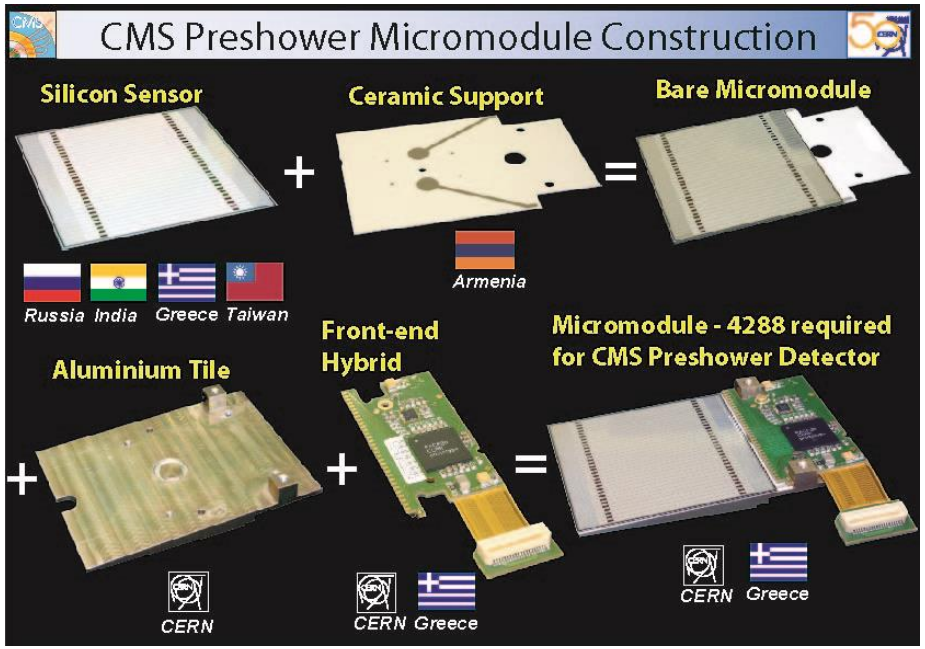
Data taking and Physics Measurements (2009 – today)

Searches

SM	*(W/Z cross sections, Wγ, Zγ, aTGCs)*
TOP	*(jets multiplicity in top-pairs, W helicity in top-pairs)*
HIGGS	*(associate production of Higgs with top-pairs)*
B2G	*(heavy top pairs, generic Dark Matter)*
EXOTICA	*(heavy boson resonances)*
SUSY	*(γ+ missing E_T , γ+jets+missing E_T , 2γ+ missing E_T , Gauge mediated SUSY)*

PAST : ECAL Preshower





14 years of development and construction

- Silicon Detectors design & fabrication
  (Joint activity with the Microelectronics Institute)
- 600/4288 micromodules assembled by INPP

Close collaboration with the Greek Industry
4500 Hybrid electronic modules built by PRISMA SA

Greek Contribution: ~ 1.3 Meuro
Industry Return: ~ 300 Keuro

CMS INDUSTRIAL AWARD 2009

GOLD AWARD to

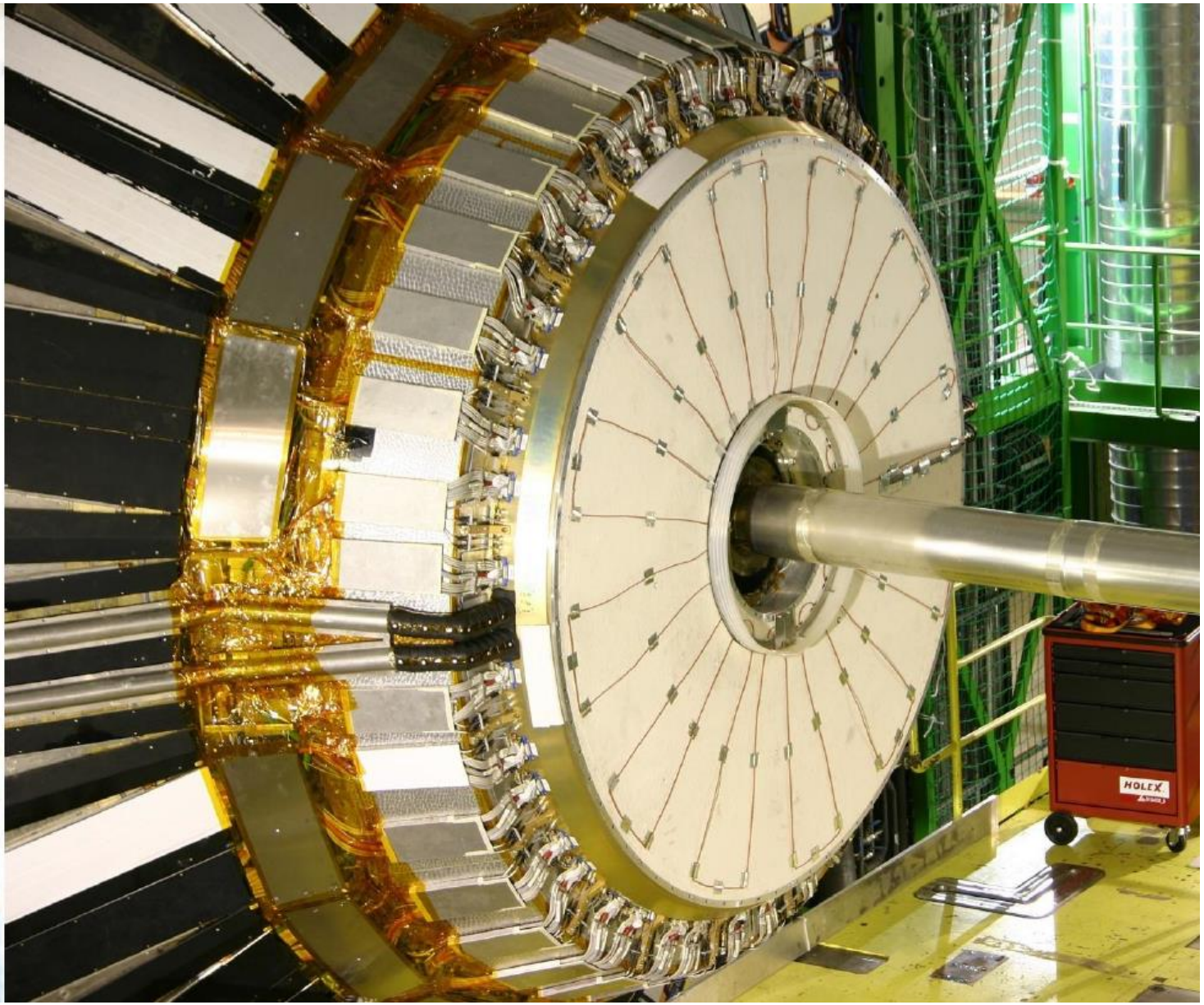
PRISMA ELECTRONICS S.A.,

Alexandroupolis (Greece)

The front-end hybrid PCB for the CMS Preshower was a very challenging project. In addition to producing the PCB itself, the mounting of the components (particularly a 196-pin BGA package) whilst keeping the delicate gold bond pads clean etc. involved some lengthy manual operations. Prisma were selected to assemble and test these pieces, a task that they carried-out with patience and diligence. Of particular note was their flexibility: the initial difficulties with producing a suitable PCB meant that their part of the project took two years longer than originally foreseen. During this long period they collaborated with us closely and were always willing to put our project ahead of others in their queue, due to our strict time constraints. The end-product speaks for itself: the number of accepted pieces, that passed all our specifications, was very close to 100%.

Proposed by Philippe Bloch/Dave Barney

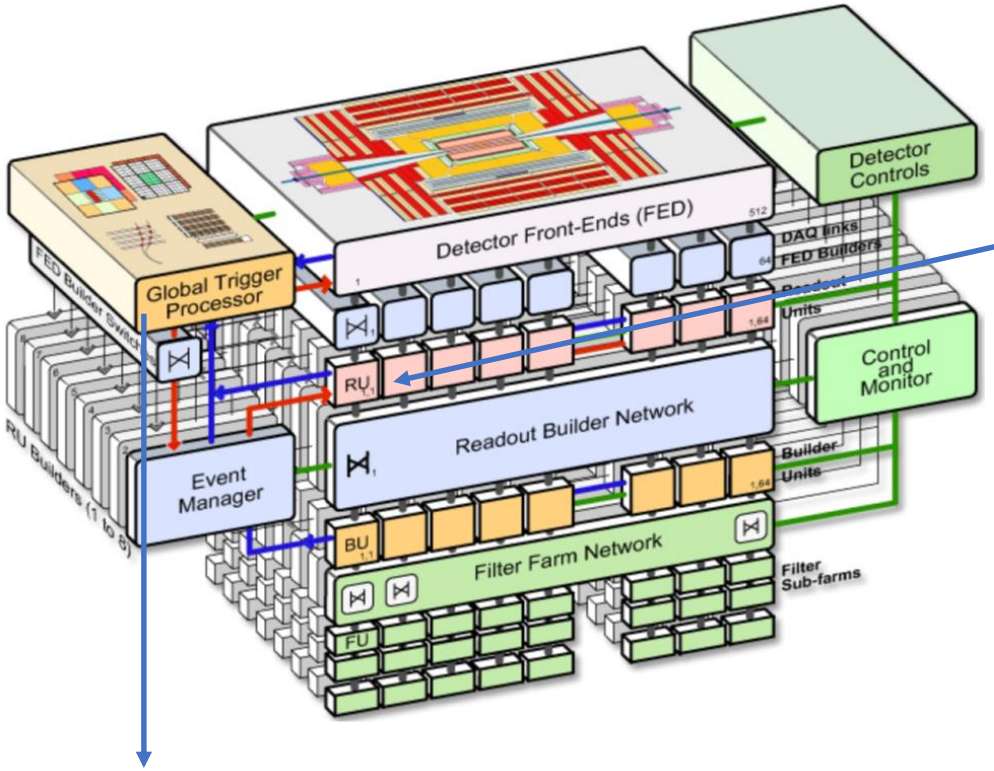
PAST : ECAL Preshower



Installation completed in Apr'09

PAST : Trigger and DAQ System (TriDas)

TriDas: **LHC collisions at 40 MHz,** **Level-1 Trigger at 100 kHz,** **High Level Trigger at 100 Hz**



Read Out Units (Rus) (completed in 2001)

Constructed and tested in collaboration with Greek Industry, 22 RU units (IOPs)

Validated the feasibility of the Trigger and DAQ System

IOP card with on board CPU, 3 PCI buses Altera FPGA

Global Trigger Processor Emulator – GTPe:

10 Full systems delivered to CMS. Designed, Built, mounted and tested at INPP.

FPGA 400kGates (Mixed firmware VHDL and Handel-C) developed at INPP.

Capabilities:

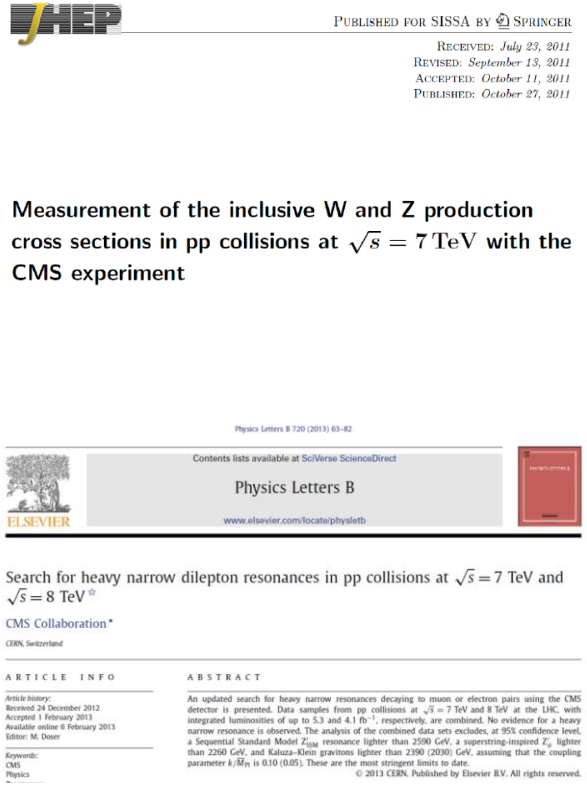
Random Triggers up to 4 MHz (nominal 100kHz), Event Packaging, Communication to Event Manager, Accept backpressure signals from detectors and DAQ partitions

PAST : Physics

Physics Studies during the Preparatory phase (up to 2009)

- *π^0 rejection: Major background for the H→ γγ*
- *Test Beam activity : 2006-2007 ECAL ENDCAP calibration*
- *Studies on discovery potential for SUSY channels, FCNC on top quark, Little Higgs, MSSM Higgs*

Physics Measurements using data from 7 & 8 TeV p-p collisions


PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: July 23, 2011
REVISED: September 13, 2011
ACCEPTED: October 11, 2011
PUBLISHED: October 27, 2011

Measurement of the inclusive W and Z production cross sections in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ with the CMS experiment

Physics Letters B 720 (2013) 63–82

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for heavy narrow dilepton resonances in pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV

CMS Collaboration*

CERN, Switzerland

ARTICLE INFO

Article history:
Received 24 December 2012
Accepted 1 February 2013
Available online 6 February 2013
Editor: M. Doser

Keywords:
CMS
Physics

ABSTRACT

An updated search for heavy narrow resonances decaying to muon or electron pairs using the CMS detector is presented. Data samples from pp collisions at $\sqrt{s} = 7$ TeV and 8 TeV at the LHC, with integrated luminosities of up to 5.3 and 4.1 fb^{-1}, respectively, are combined. No evidence for a heavy narrow resonance is observed. The analysis of the combined data sets excludes, at 95% confidence level, a Sequential Standard Model Z_{SM} resonance lighter than 2590 GeV, a superstring-inspired Z_ψ lighter than 2260 GeV, and Kaluza–Klein gravitons lighter than 2390 (2030) GeV, assuming that the coupling parameter $k/\bar{M}_{Pl}$ is 0.10 (0.05). These are the most stringent limits to date.

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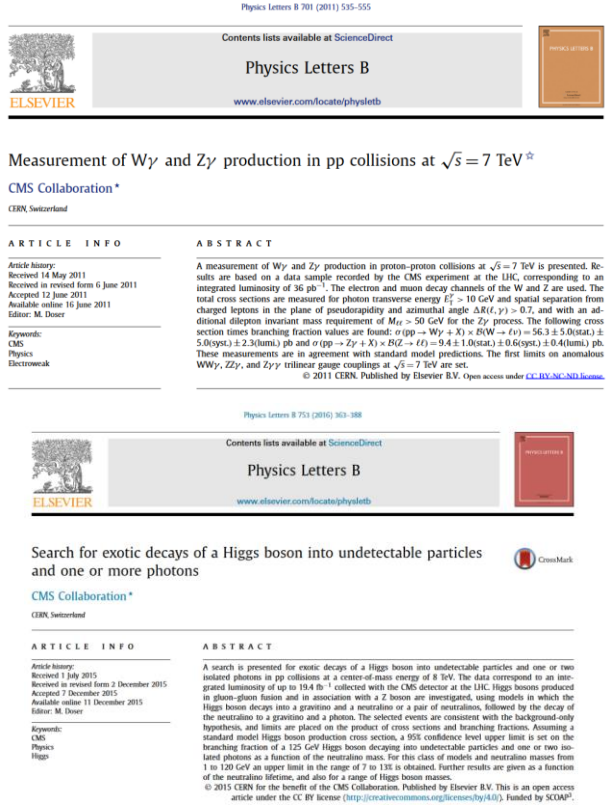
Physics Letters B 701 (2011) 535–555

Contents lists available at ScienceDirect

Physics Letters B

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Measurement of Wγ and Zγ production in pp collisions at $\sqrt{s} = 7$ TeV

CMS Collaboration*

CERN, Switzerland

ARTICLE INFO

Article history:
Received 14 May 2011
Received in revised form 6 June 2011
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Available online 16 June 2011
Editor: M. Doser

Keywords:
CMS
Physics
Electroweak

ABSTRACT

A measurement of Wγ and Zγ production in proton–proton collisions at $\sqrt{s} = 7$ TeV is presented. Results are based on a data sample recorded by the CMS experiment at the LHC, corresponding to an integrated luminosity of 36 pb^{-1}. The electron and muon decay channels of the W and Z are used. The total cross sections are measured for photon transverse energy $E_T^\gamma > 10$ GeV and spatial separation from charged leptons in the plane of pseudorapidity and azimuthal angle $\Delta R(\ell, \gamma) > 0.7$, and with an additional dilepton invariant mass requirement of $M_{\ell\ell} > 50$ GeV for the Zγ process. The following cross section times branching fraction values are found: $\sigma(pp \to W\gamma + X) \times B(W \to \ell\nu) = 56.3 \pm 5.0(\mathrm{stat.}) \pm 5.0(\mathrm{syst.}) \pm 2.3(\mathrm{lumi.})$ pb and $\sigma(pp \to Z\gamma + X) \times B(Z \to \ell\ell) = 9.4 \pm 1.0(\mathrm{stat.}) \pm 0.6(\mathrm{syst.}) \pm 0.4(\mathrm{lumi.})$ pb. These measurements are in agreement with standard model predictions. The first limits on anomalous WWγ, ZZγ, and Z$\gamma\gamma$ trilinear gauge couplings at $\sqrt{s} = 7$ TeV are set.

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Physics Letters B 753 (2016) 363–388

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for exotic decays of a Higgs boson into undetectable particles and one or more photons

CMS Collaboration*

CERN, Switzerland

ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form 2 December 2015
Accepted 7 December 2015
Available online 11 December 2015
Editor: M. Doser

Keywords:
CMS
Physics
Higgs

ABSTRACT

A search is presented for exotic decays of a Higgs boson into undetectable particles and one or two isolated photons in pp collisions at a center-of-mass energy of 8 TeV. The data correspond to an integrated luminosity of up to 19.4 fb^{-1} collected with the CMS detector at the LHC. Higgs bosons produced in gluon–gluon fusion and in association with a Z boson are investigated, using models in which the Higgs boson decays into a gravitino and a neutralino or a pair of neutralinos, followed by the decay of the neutralino to a gravitino and a photon. The selected events are consistent with the background-only hypothesis, and limits are placed on the product of cross sections and branching fractions. Assuming a standard model Higgs boson production cross section, a 95% confidence level upper limit is set on the branching fraction of a 125 GeV Higgs boson decaying into undetectable particles and one or two isolated photons as a function of the neutralino mass. For this class of models and neutralino masses from 1 to 120 GeV an upper limit in the range of 7 to 13% is obtained. Further results are given as a function of the neutralino lifetime, and also for a range of Higgs boson masses.

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Leading Roles in Physics Groups

- **Convener** of the Vector Boson Task Force (VBTF) group (2010+2011)
- **Editors** of papers
- **Conferences** on behalf of CMS Collaboration
- **Analysis Review Committees** chairs/members
- **Institutional Reviews** for papers before publication

PRESENT : The CMS/INPP team

Permanent Staff (Researchers)

1) Anagnostou Georgios
2) Daskalakis Georgios
3) Kyriakis Aristotelis
4) Loukas Dimitrios

+3 ex-members

Post Docs

none

+7 ex-members

Electronics Engineers

1) Kazas Giannis

+1 ex-members

Administrative

1) Barone Michele

Doctoral Students

1) Paspalaki Garyfallia
2) Asenov Patrick
3) Assiouras Panagiotis
4) Stakia Anna

+9 ex-members

Non-Doctoral Students

1) Papadopoulos Alkiviadis

+1 ex-member

EDUCATION:

PhDs: 6 completed,
4 ongoing

1) Paspalaki G., *writing*
2) Asenov P., funded for 3y
3) Assiouras P., funded for 2y
4) Stakia A. , funded for 1y

PRESENT : The Phase II CMS Upgrade

Trigger/DAQ

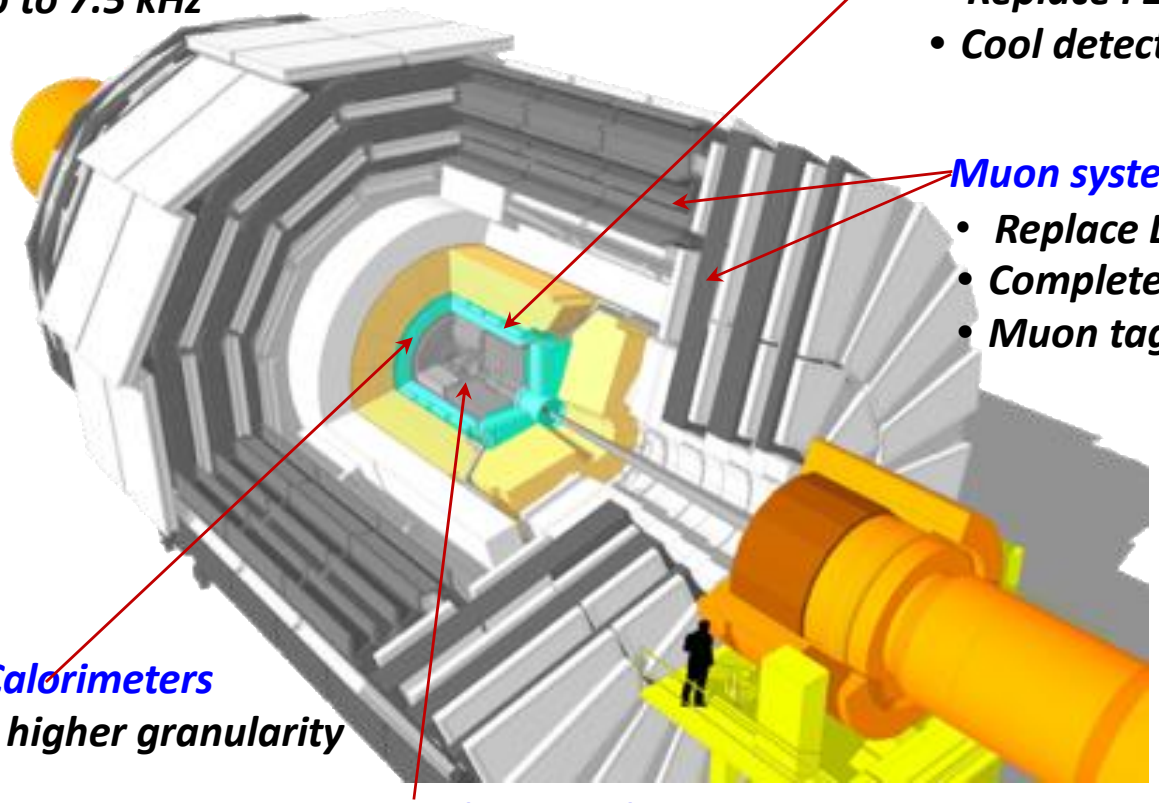
- ***L1 with track up to 750 kHz - 12.5 μs latency***
- ***HLT output up to 7.5 kHz***

Barrel EM calorimeter

- ***Replace FE electronics***
- ***Cool detector APDs***

Muon systems

- ***Replace DT & CSC FE electronics***
- ***Complete RPC coverage***
- ***Muon tagging 2.4 < η < 3***



Replace Endcap Calorimeters

- ***Rad. Tolerant - higher granularity***

Replace Tracker

- ***High granularity – less material- b eff- p_T resolution***
- ***Selective readout of outer tracker at 40 MHz for L1 trigger***
- ***Extend η coverage to 4***

PRESENT : The Phase II CMS Upgrade

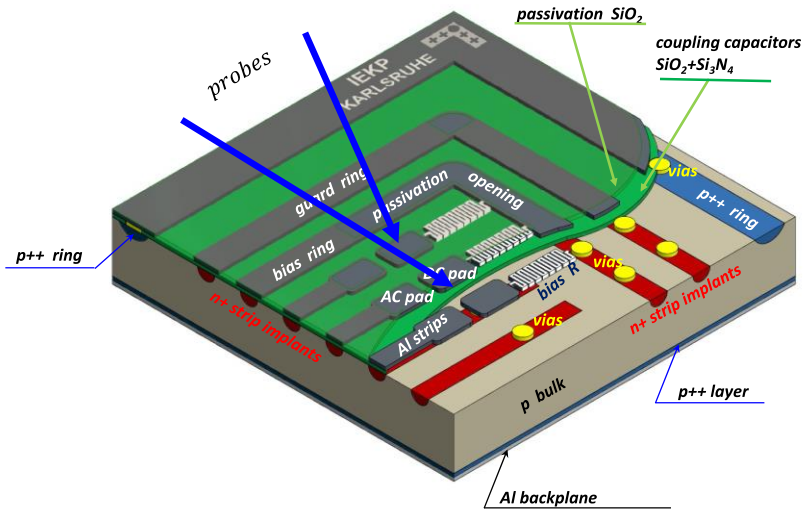
Total Tracker Replacement

Radiation Tolerance up to $\int Ldt = 3000\ fb^{-1}$	Flip from p_on_n sensors to n_on_p
Pile Up 140-200 , Occupancy < 1 %	Increase granularity
Longer Latency : from 3.2 μs to 12.5 μς	Increase front end buffer depth
Increase forward acceptance	Mostly through pixel extension
Improve CMS Trigger	Provide tracking info to L1
Improve resolution at low P_t	Reduce material
Improve resolution at high P_t	Increase granularity

PRESENT : R&D activities for the Phase II CMS Tracker

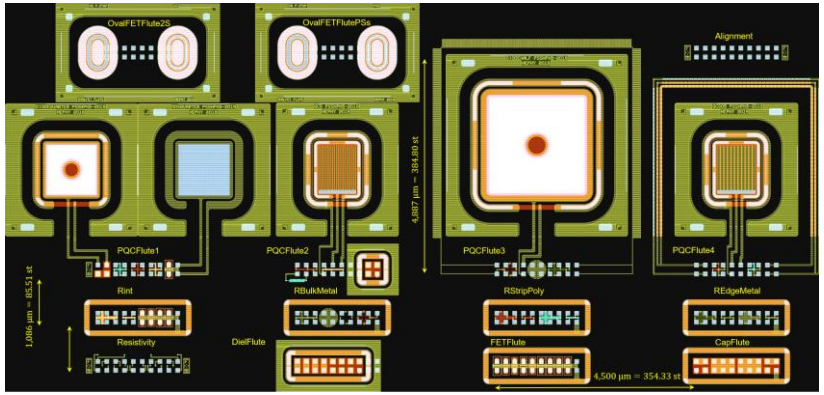
10 years of R&D
Over 100 MCHF core cost
Greek contribution
1.4 MCHF foreseen

Electrical characterization of silicon sensors



Measurements of capacitances and leakage currents of individual strips

Process Quality Control (PQC) for the mass production of sensors for the outer part of the CMS Phase II tracker (OT)

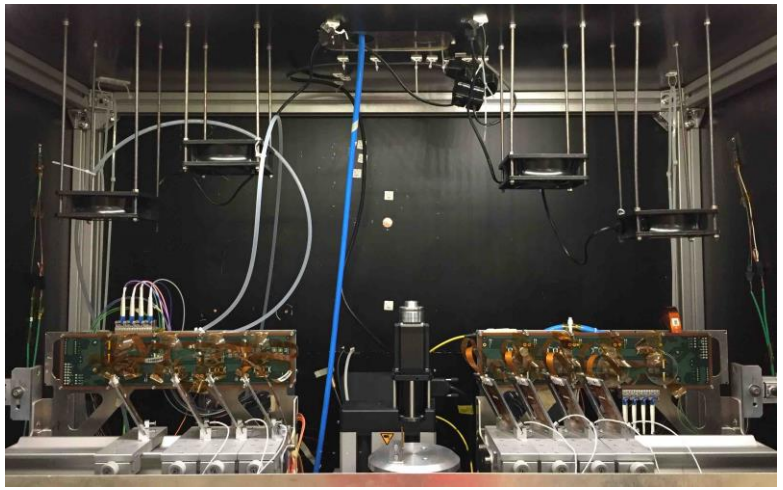


- extract critical process parameters from dedicated test structures
- ensure that the sensor production process remains stable

CMS-INPP is **one of the four** groups of CMS collaboration **committed** for the PQC of the OT sensors.

With a total production of 26592 + spares, test structures from about the 20% of the total production will be measured ⇒ 1400 wafers per center

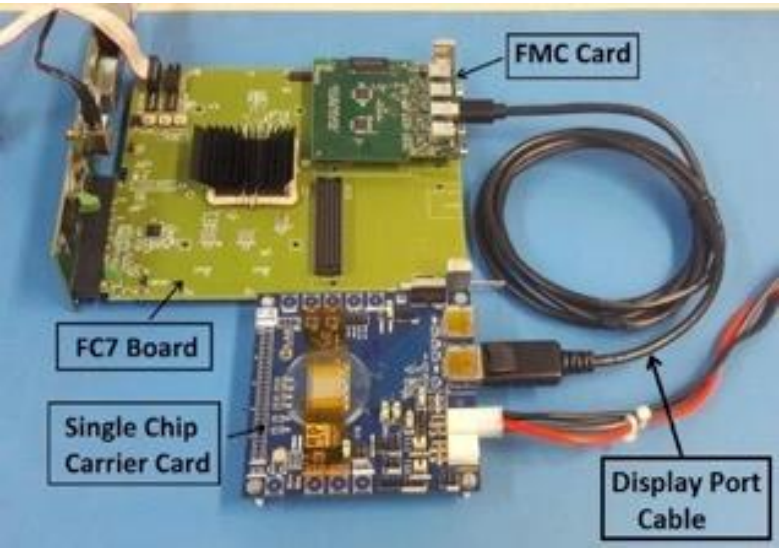
PRESENT : R&D activities for the Phase II CMS Tracker



New particle telescope @ 40 MHz *for beam tests of sensors and electronics*

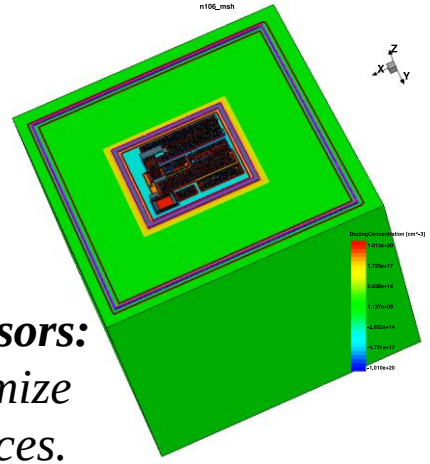
^{60}Co radiation Tests in collaboration with Greek Atomic Energy Commission

main radiation : charged particles & neutrons
Complementary study with gamma rays will improve understanding the radiation degradation of sensors.



Firmware for the Pixel Detector:

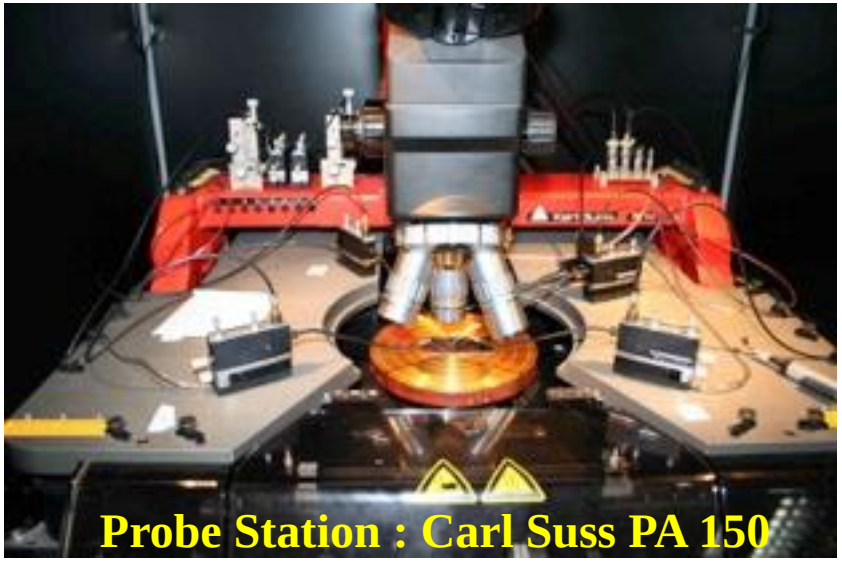
CMS-INPP contributes to the development of the firmware for the Read-Out electronics
- CMS DAQ testing and
- development platform for the pixel



TCAD simulation of silicon sensors:

use of computer simulations to develop and optimize semiconductor processing technologies and devices.

PRESENT : Infrastructure / DIL


Probe Station : Carl Suss PA 150


Electrical characterization equipment

Detector **I**nstrumentation **L**aboratory
a Lab for microsystems
development
&
packaging


Wire Bonding (Delvotec 5430)

Climatic Chamber

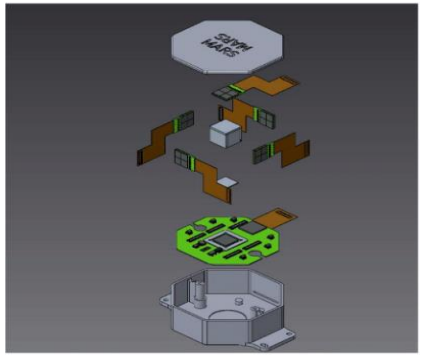

Switch Matrix Mainframe

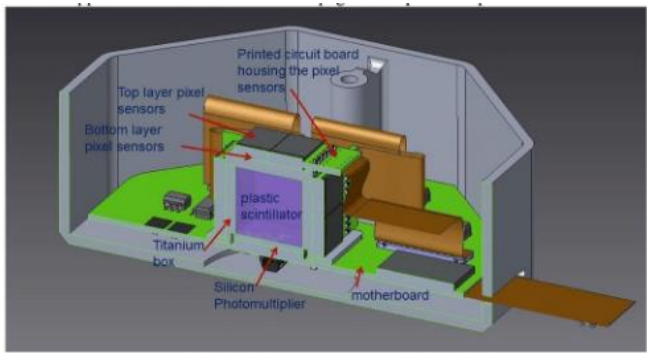
The MIDAS Radiation Detector

An ESA project in collaboration with the Greek Industry based on High Voltage CMOS (HVCMOS) technology

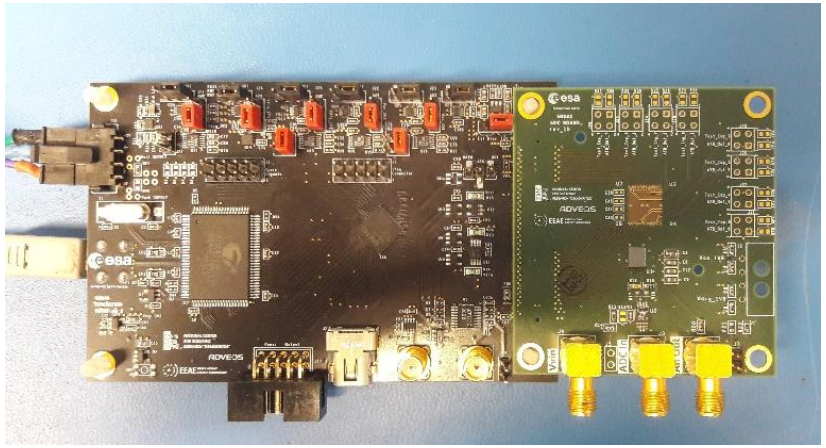
MIDAS: highly miniaturized radiation detector for use in space applications with technology transfer from HEP.

Detecting Head consists of 40 HVCMOS ASICs (32 x 32)
&
the Neutron Monitor subsystem.





Evaluation Board and DAQ system by I. Kazas.



A second version of the ASIC is submitted for fabrication

Spin Offs:
Scientists, engineers and technicians, who acquired **technical skills** and **know how** in our laboratory ,
either have created their own company or
are employed by Greek & international industrial companies (***e.g. Broadcom Hellas, Synopsis, European Sensor Systems, INTRACOM, ADVEOS***).

PRESENT : Physics

data : 2016-2017-2018 **13** TeV , **140** fb^{-1}

HIGGS

Study of the di-leptonic ttH(H→bb) channel **reconstructing the Higgs mass** and using a **data-driven background** prediction method. ***ongoing***

B2G

Searching **simultaneously** for both a **heavy top partner T'** and a **new gauge boson W'**. ***ongoing***

TOP

Measurement of the W helicities using semileptonic top-pair decays. **New Physics** from anomalous Wtb couplings. **New Methods** to improve systematics. ***ongoing***

EXOTICA

Search for a **narrow resonance** in high-mass dielectron & dimuon final states. Analysis approved. Long paper (**legacy**) under preparation.

SUSY

Search for general gauge-mediated supersymmetry in final states with two photons and missing transverse momentum. **Publication:** JHEP06 (2019) 143, https://doi.org/10.1007/JHEP06(2019)143

PRESENT : Physics

We would like to stress that:

A) Whatever we do **now** is based on **past** experience. We continuously **build up** expertise and constantly **enlarge** the "phase space" of our physics measurements.

examples:
W & Z cross section measurements with electrons $\Rightarrow$ heavy resonance searches ($Z' \rightarrow e^+e^-$)
ttbar+Njets cross section measurements $\Rightarrow$ W helicities from top-pairs , heavy T'T' searches
expertise on photons (preshower) $\Rightarrow$ SUSY searches with photons (+ jets / MET)

B) We have built **strong** International & Domestic Collaborations.
Makes physics analysis much easier & more enjoyable.

examples:
Collaboration with University of Athens in ttH analysis
Collaboration with IIHE-ULB, RAL, CIEMAT, Florida State University, University of Notre Dame, Purdue University

PRESENT : EXOTICA Workshop 2018

CMS EXO WORKHOP 2018

1st- 3rd November 2018

National Kapodistrian University of Athens (NKUA) Greece

Local Organizing Committee

Charis-Kleio Koraka, NKUA
Niki Saoulidou, NKUA
Georgios Anagnostou, NCSR Demokritos
Georgios Daskalakis, NCSR Demokritos
Kostas Kousouris, NTUA

Scientific Organizing Committee

Oliver Buchmuller, Imperial College, UK
Ivan Mikulec, HEPHY, Austria
Adish Vartak, CERN

Email /contact : cms-exo-athens-2018@cern.ch
Indico Page : https://indico.cern.ch/event/733957/

FUTURE : Building the Phase II CMS Detector

Commitments for the Phase II CMS upgrade, challenges and risks

SWOT (Strength, Weaknesses, Opportunities and Threads)

Strengths: Based on the expertise acquired in the course of the past fifteen years, DIL is established as the principal Greek national laboratory in the field of solid-state sensors and related VLSI read out electronics for radiation detector systems. A strong Physics analysis group is in place.

Weaknesses: Innovative and internationally standing work on nano and micro assembly and packaging requires advanced and expensive equipment that is extremely difficult to be funded with national resources, especially in the current fiscal situation of Greece.

Opportunities: One of the national research policy decisions is targeting the field of Microelectronics & Embedded Systems. This, with a number of new and rapidly growing SMEs creates new opportunities for increased collaborations at national level.

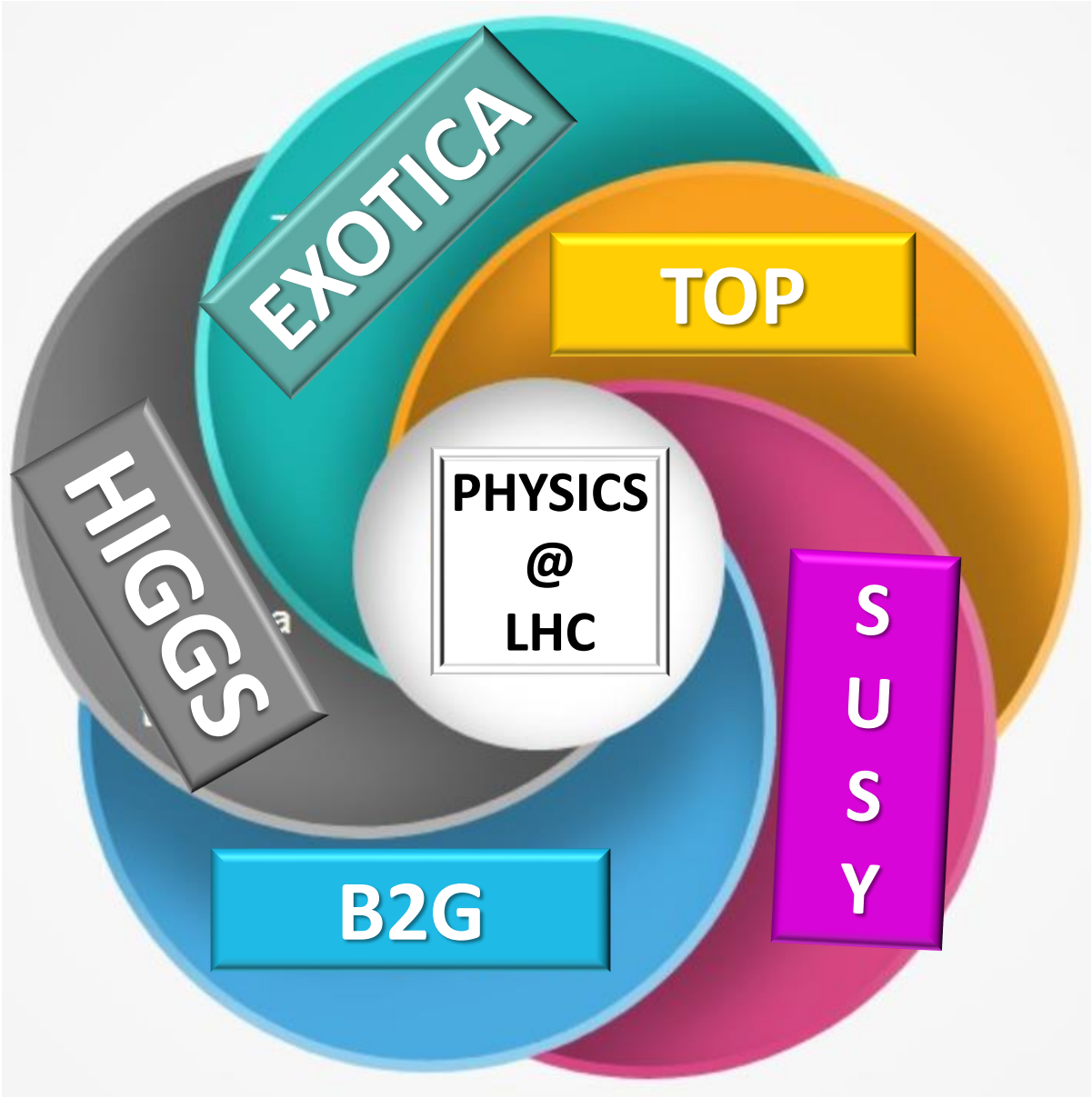
Threads: Lack of regular financial support from the Greek government, strong dependence of EU resources and low level of domestic industrial activity create a volatile research environment.

FUTURE : Physics

Run-2
13 TeV
140 fb^{-1}

in 2y from now

Run-3
14 TeV
300 fb^{-1}



Targets

Harvest Run-2 results
(best possible
reconst. & calibrations)

Preparations for Run 3

Other activities of the CMS group

Service work for CMS

Every CMS member who signs papers should offer 4 months of service work to several areas necessary for the good operation of the experiment.

Analysis Review Committees (ARC)

Senior members of the experiment are regularly asked to participate or chair Internal Review Committees which are assigned to each Physics Analysis before its results become public.

Institutional Review – Collaboration Wide Review

After the approval of a Physics Result from the Collaboration, the draft of the paper is reviewed from Institutes/Universities which are randomly selected from the Collaboration.

Education/Outreach activities

Members of the group participate/organize various educational & outreach activities

- **Supervise** graduate students for the completion of their degree (**MSc**/**PhD**) as well as undergraduate students during their **Diploma** thesis or during their **practical training**.
- Particle Physics **Masterclasses** for high school students
- Summer Schools
- Researcher's Night
- Popularized science lectures to public or school audiences

Publications 2016-2019

486 papers found, 486 of them citeable (published or arXiv)

Source: Inspire

Citation summary results	Citeable papers	Citeable papers excluding self cites	Citeable papers excluding RPP	Published only	Published only excluding self cites	Published only excluding RPP
Total number of papers analyzed:	486	486	0	426	426	0
Total number of citations:	17,813	10,178	0	17,579	10,034	0
Average citations per paper:	36.7	20.9	0.0	41.3	23.6	0.0
Breakdown of papers by citations:						
Renowned papers (500+)	2	1	0	2	1	0
Famous papers (250-499)	4	0	0	4	0	0
Very well-known papers (100-249)	21	7	0	21	7	0
Well-known papers (50-99)	66	37	0	66	37	0
Known papers (10-49)	256	234	0	249	232	0
Less known papers (1-9)	103	161	0	78	136	0
Unknown papers (0)	34	46	0	6	13	0
h_{HEP} index [?]	65	48	0	65	48	0

CMS-INPP contribution in numbers (2016-2019):

CMS-INPP as primary Authors/Editors/Contact Persons

Publications in referred journals : 8
Published preliminary CMS results : 4
Analysis Notes, Internal to CMS : 13

Conferences/Workshops : 9
Analysis Review Committees : 9
Institutional Reviews : 11

The INPP/CMS Group funding (2016-2019)

- ***KRHPIS-II***
  CMS-INPP group : 82350 euros
- ***Detector Development and Technologies for High Energy Physics and Applications(DeTAnet)***
  Infrastructure program for HL-LHC: 78760 euros
- ***Development of Silicon sensors for high luminosities at the LHC*** (P. Asenov)
  Hellenic Foundation for Research & Technology : 27000 euros
- ***Silicon sensors for the upgrade of the HL-LHC experiments*** (P. Assiouras)
  Hellenic Foundation for Research & Technology : 27000 euros
- ***Highly Miniaturized ASIC Radiation Detector (MIDAS)***
  European Space Agency (Collaboration with the ADVEOS company): 40000 euros
- ***New generation of sensors and electronics for the upgrade of the CMS***
  National Strategic Reference Framework (NSRF, ΕΣΠΑ): 40000 euros

total 295 000

"Development of the Phase II Silicon Tracker and Physics in the CMS Experiment at CERN"
Hellenic Foundation for Research & Innovation (ΕΛΙΔΕΚ): **Budget of 1,2 M €.**
Proposal **under evaluation** in the framework of enhancing the Greek research infrastructure.

Closing remarks

The **Phase II CMS Tracker Upgrade** is our flagship project on **instrumentation / detector development**.
We are in a good path to fulfil our commitments. Funding is an issue.

The **Physics Analysis** Group has accumulated a lot of experience from Run-1 and Run-2.
Run-3 might give us another opportunity for discoveries. More funded PhD students are necessary.

We have a clear program of action for the following years, both on **Instrumentation** and on **Physics**.

We suffer from serious funding problems:

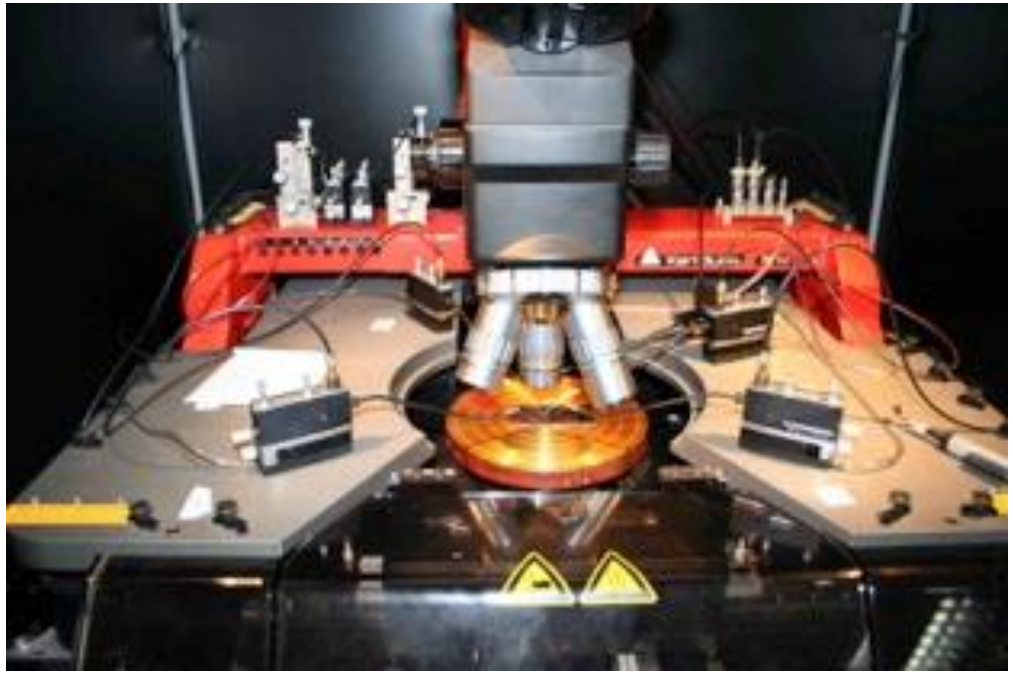
A) No regular funding. Funding calls almost random. Very difficult to plan our Research and make important Commitments.

B) NSCR Funding of PhD students & PostDocs stopped in 2012.

C) Lack of PhD students & PostDocs. Extremely difficult to provide them support but we really need them.

BACKUP

PRESENT : Infrastructure / DIL



Probe station: Carl Suss PA 150
A semiautomatic probe station for probing microelectronic devices up to 10 inches.

Electrical Characterization Equipment:
Equipment to measure capacitances, currents and various electrical parameters of microelectronic devices.

PRESENT : Infrastructure / DIL

Wire Bonding Machine:
A machine for wire interconnections of microelectronics devices.

Climatic Chamber:
A climatic chamber with the capability to go from -42 ^{o}C to +180 and from 10 to 94% Relative Humidity.

Switch Matrix Mainframe:
switch system optimized for semiconductor test application.

Proposal under evaluation

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Proposal **under evaluation** in the framework of enhancing the Greek research infrastructure.

The Goal of the present proposal is the development at NCSR of a **state-of-the-art European laboratory for characterization of nano and micro devices** along with **assembly and packaging of associated system**.

New equipment :
Fully automated wire bonder, Semiconductor analyzer, New Probe station, Clean room, Oscilloscopes, power supplies, peripheral instrumentation, EDA (Electronics Design) packages, + 2 engineers