CY-CERN Committee, June 2021

The Participation of Cyprus in the CERN Scientific Programme & Perspectives for the Future

P. Razis, Scientific Delegate of Cyprus at CERN

Contents

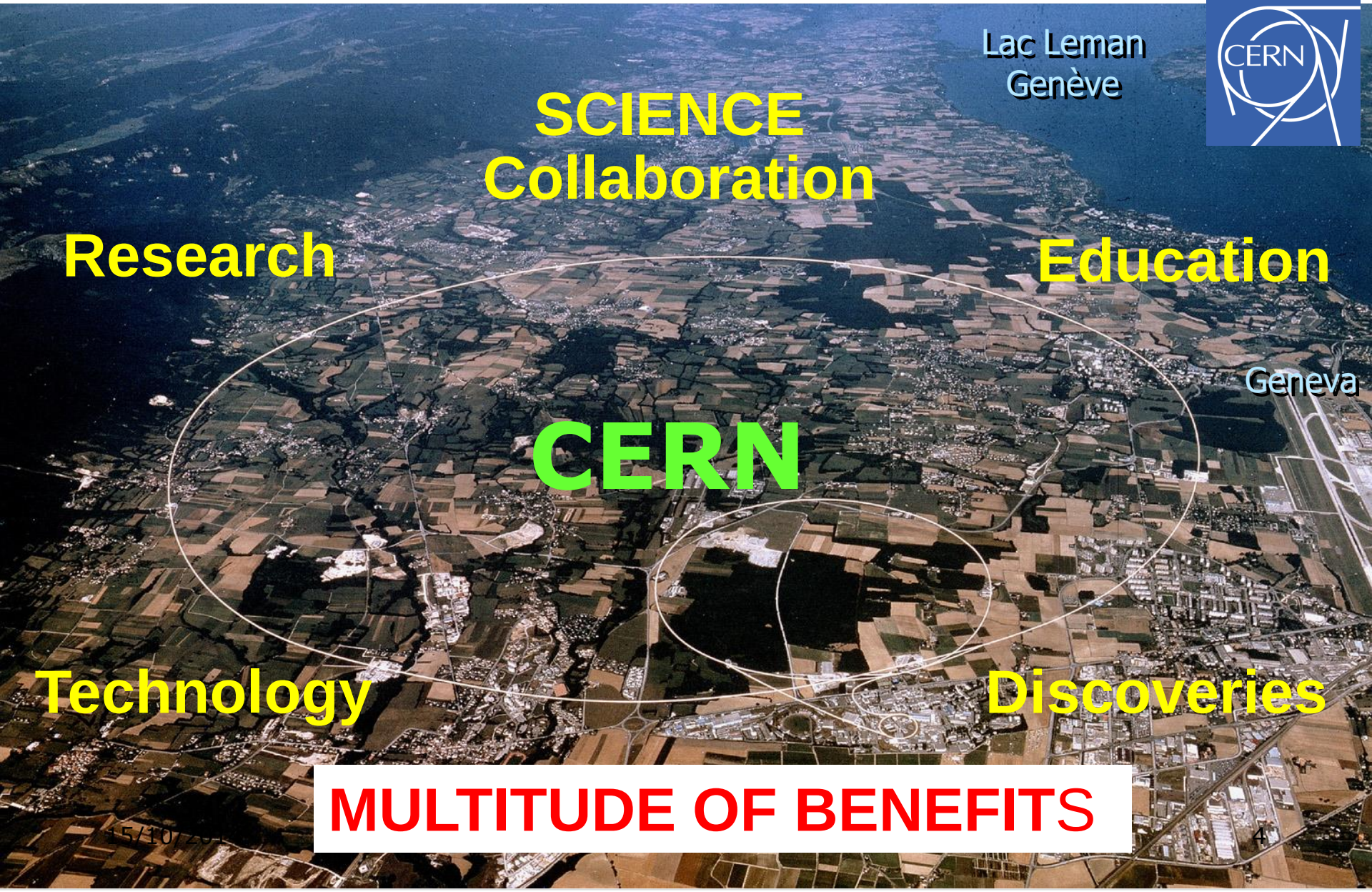
- Introduction / History of Cyprus at CERN
- UCY- HEP Group
- Contributions* to the L3 Experiment at LEP
- Contributions* to the CMS Experiment at LHC
- Perspectives for the Future
- Problems and Solutions
- Conclusions

*for 1986-2020 only a synopsis is provided here. More details can be found in other presentations I submitted to the CY-CERN Committee.

History of Cyprus @ CERN

1986, October 1:	Joined the L3 Experiment at LEP, CERN
1992, September 7:	High Energy Physics Laboratory founded, UCY
1995, December 12:	Joined the CMS Experiment at LHC, CERN
1999, March 23:	MoU signed - Participation in CMS (NMS)
2004, May 1:	Cyprus joins European Union
2004, December 16:	CERN Council approved Co-operation Agreement
2006, February 14:	Non-Member State Status
2009, June 5:	Application for a Member State
2012, October 5:	Signature to become Associate Member State
2016, April 1:	Associate Member State, pre-stage to membership
2021, March 31:	5-year period ends

European Organization for Nuclear Research



Introduction

State Universities

University of Cyprus (1992) ->Collaborate at CERN since 1992

Open University of Cyprus (2006)

Cyprus University of Technology (2007)

Private Universities

Frederick University (2007)

European University Cyprus (2007)

University of Nicosia (2007)

Neapolis University (2011)

University of Central Lancashire (2012)

Philips University (2019)

Research Institutes

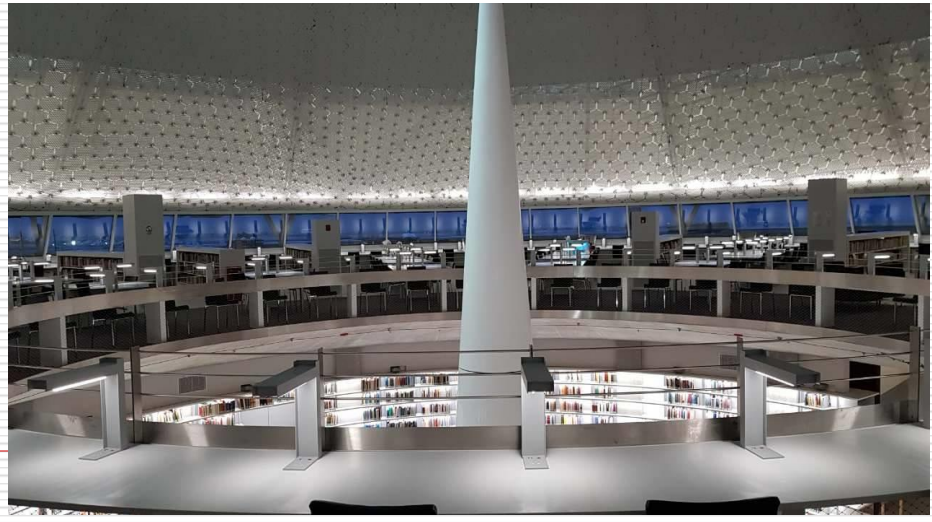
Agricultural Research Institute (1962)

State General Laboratory (1970)

The Cyprus Institute of Neurology & Genetics (1990)

The Cyprus Institute (2005)

University of Cyprus Campus



UCY-HEP Group

Current Members of the Group:

P. Razis	Professor
F. Ptochos	Associate Professor
H. Saka	Lecturer
J. Mousa	Research Associate
A. Attikis	Research Associate
E. Dimovasili	External Member of Group
K. Gouranga	Research Associate
H. Rykaczewski	Emeritus
C. Nicolaou	MSc, Electronics Engineer
M. Constantinou	Computer Engineer
M. Kolosova, **S. Constantinou** **C. Christoforou**	PhD Students
Graduate Students	MSc Students
Undergraduate Students	Final Year Projects

Introduction

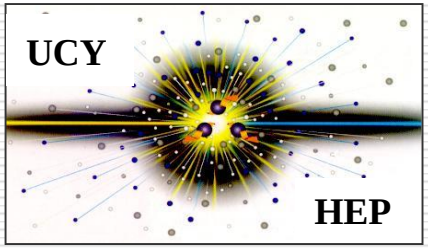
UCY- HEP Group: founded in 1992

Projects related to CERN	Status
L3 Experiment at LEP	Completed (construction, testing, data taking, monitoring systems, MC simulation, analysis)
CMS Experiment at LHC	Construction, beam tests, MC simulation, data taking, quality of data, trigger, analysis
High Performance Comp.	simulation & data processing
Dosimetry, Safety	Active dosimeters, simulation of radiation, dosimetry, safety & radiation damage
KM3NeT (ESFRI)	Neutrino Telescopy (ORCA & ARCA), calibration, Technical Design Report
COST Action FAST (EU)	Fast Advanced Scintillator Timing

UCY-HEP Group

Up to now worked in the UCY- HEP Group:

- 3 Faculty Staff
- 10 Postdoctoral Fellows, 19 Research Assistants
- 4 guest members
- 16 PhD students
- 3 Electronic Engineers
- 18 MSc students
- >60 Final Year Projects students
- 12 International Conf. (CMS Week 2008, CSC 2013, COST FAST 2017)

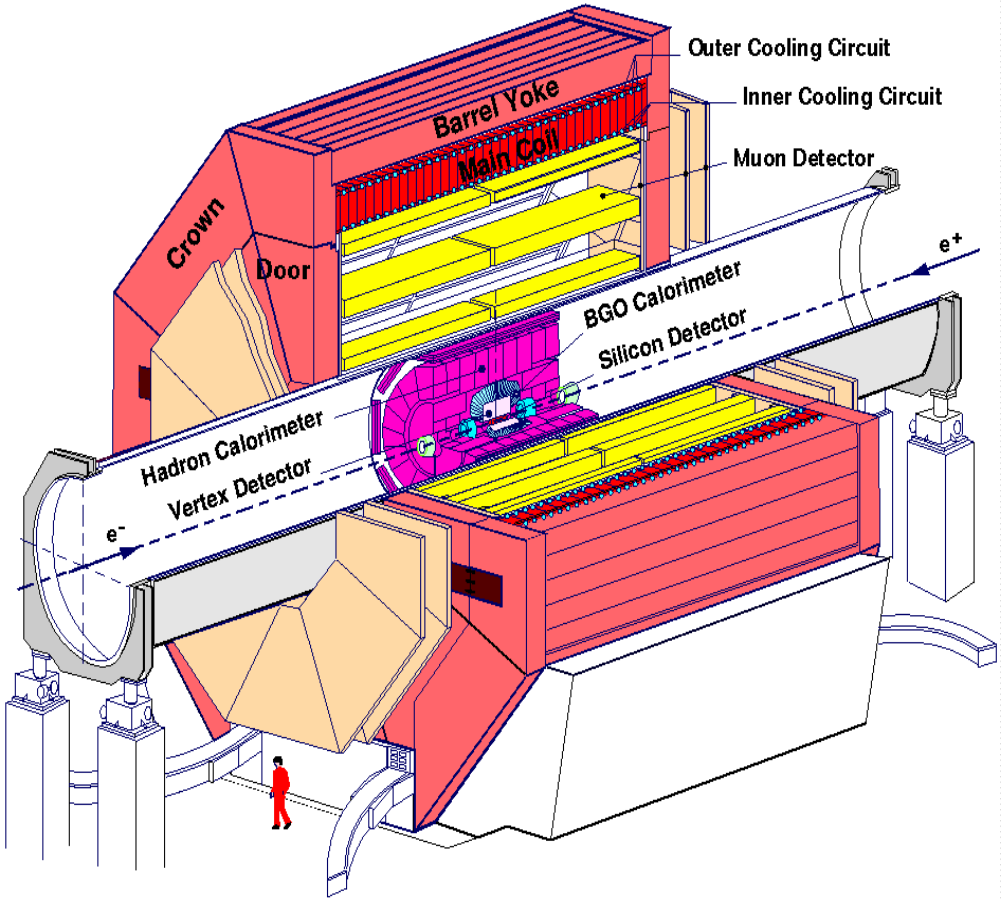


Funding

1. European Union
2. Cyprus Foundation of Research and Innovation
3. Internal Funds of the University
4. Governmental and Semi-governmental Organizations
5. CERN support

Established a strong group with international visibility

L3 Experiment at LEP (1989-2000)

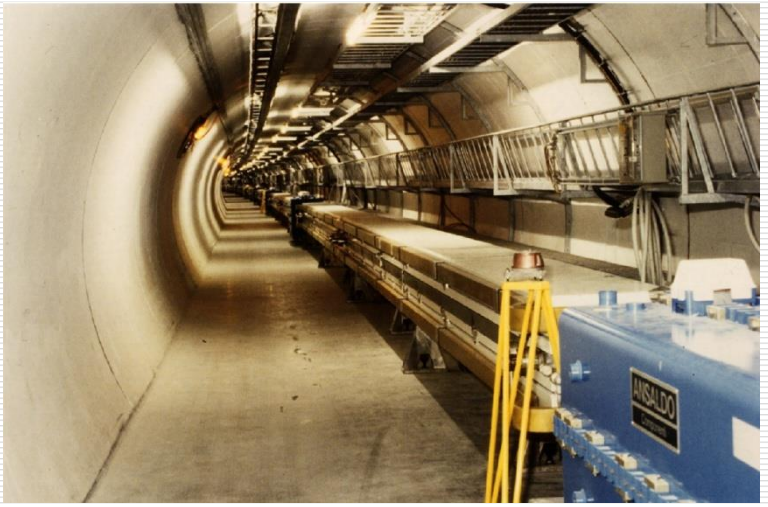


$e^+ e^- \rightarrow$ hadrons

E_{CM}= 90-209 GeV

L= ~10^{32} cm^{-2} s^{-1}

B= 0.5 Tesla



L3 Experiment **LEP tunnel**

L3 Experiment at LEP

Contributions of UCY-HEP (1989-2000)

1. Alignment of the L3 Muon Spectrometer (Laser Beacon)
2. Calibration of the L3 Muon Spectrometer (N_2 Laser)
3. Participation in Shifts and Test Beam runs
4. Quality control of Muon Spectrometer Monitoring Systems
5. Monte Carlo Simulation of rare events & exotic processes
6. Analysis of new particle searches (rare and exotic decays)

(Convenor) Direct contributions in:

Z^0 lineshape

$e^+ e^- \rightarrow Z \rightarrow e\mu, \mu\tau, e\tau$

search for excited leptons

search for MSSM higgs

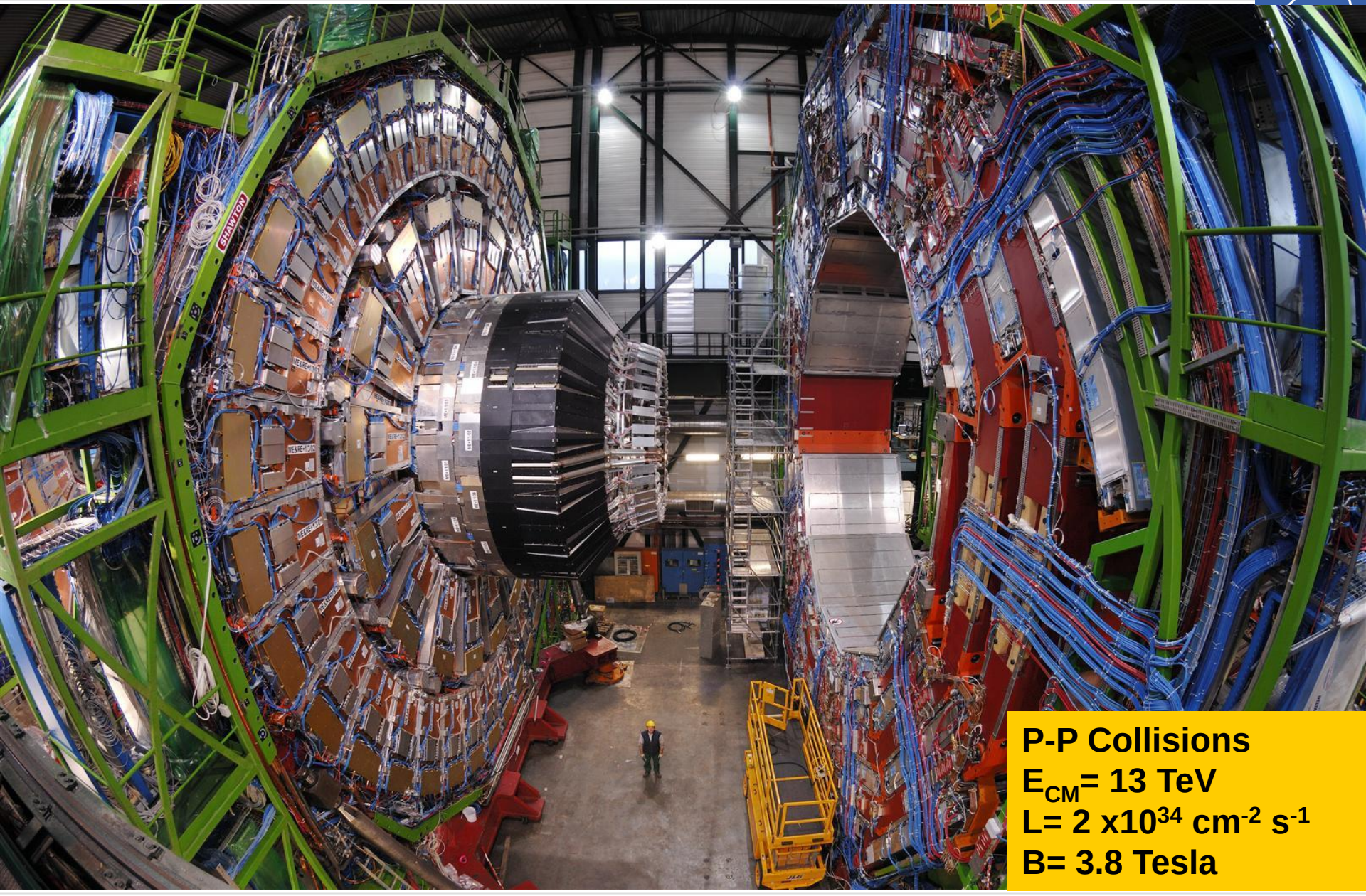
particle matching

$e^+ e^- \rightarrow \gamma\gamma(\gamma)$

search for Z'

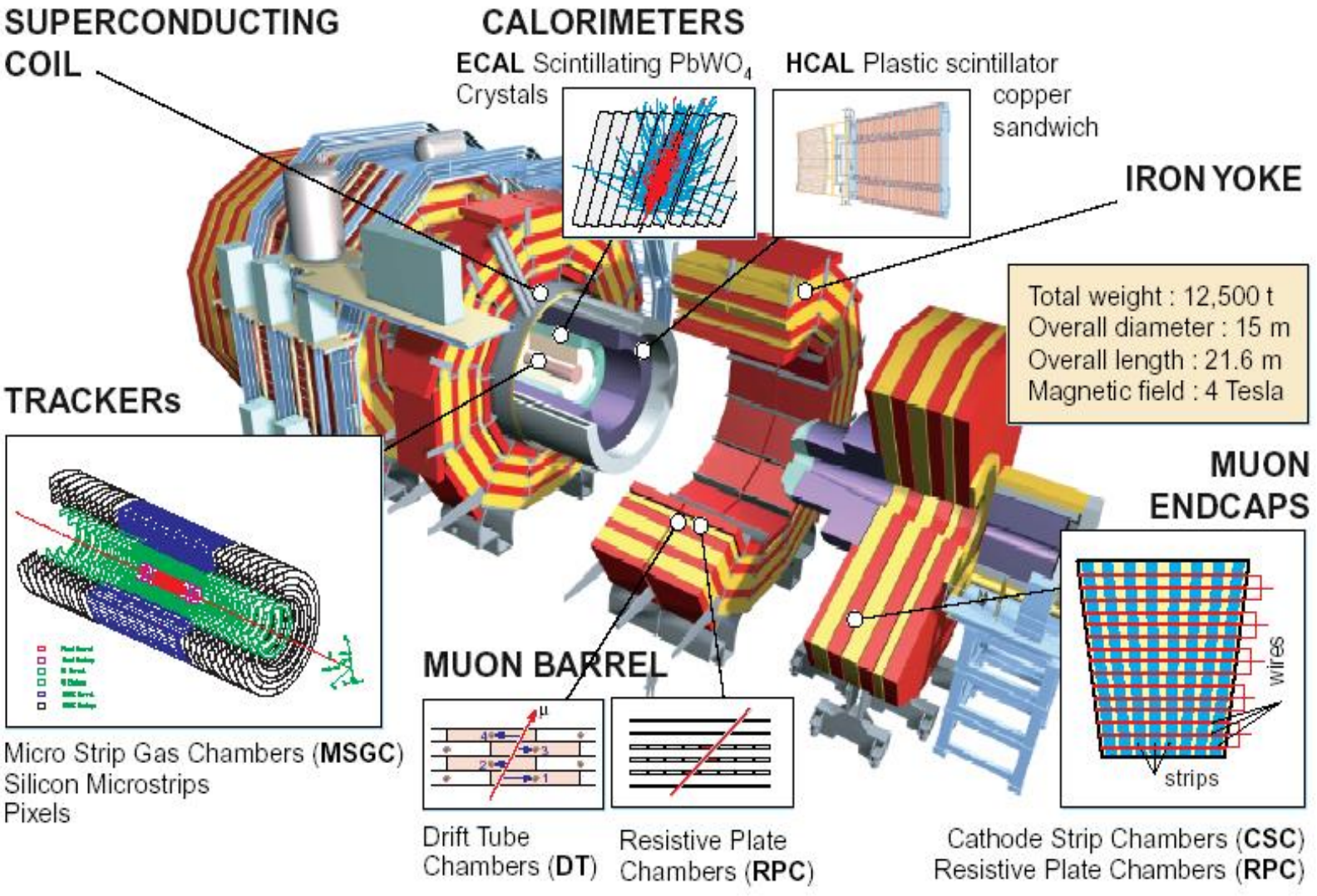
search for neutralinos

CMS Experiment at LHC



P-P Collisions
E_{CM}= 13 TeV
L= 2 x10^{34} cm^{-2} s^{-1}
B= 3.8 Tesla

CMS Detector Systems



CMS Experiment at LHC

Contributions of UCY-HEP (1995-2015)

1. Member of the Consortium for the 5 Barrel Yoke Wheels and the Vacuum Tank of the CMS Magnet
2. Participation in the construction of the CMS ECAL
3. Calibration of VFE electronics of the CMS ECAL
4. Algorithms for correcting the ECAL signal
5. Participation in Shifts and Test Beam runs
6. Quality control of the CMS Tracker Data (Convenorship)
7. Monte Carlo Simulation → LHC Computing GRID – Tier
8. Analysis → Early Resonances, Heavy Flavor Physics, Bose Einstein Correlations, searches for SM, MSSM & NMSSM higgs bosons, data quality for ECAL & Tracking, tau systematics and Trigger studies
9. Organizing Conferences & CERN Schools in Cyprus

In parallel…KM3NeT (ESFRI)

Contributions of UCY-HEP (2006-2012)

Calibration of detectors by non-ionizing radiation

1st Generation:

E_{μ}>1Gev, $A_{eff.}$~100-1000 m^2

2nd Generation: E_{μ}> 5-100 Gev

$A_{eff.}$~0.1-1km^2

LoI and TDR ready for a:

Deep-Sea Research Infrastructure in Mediterranean Sea incorporating a Very Large Volume Neutrino Telescope

ORCA: v Oscillation Research

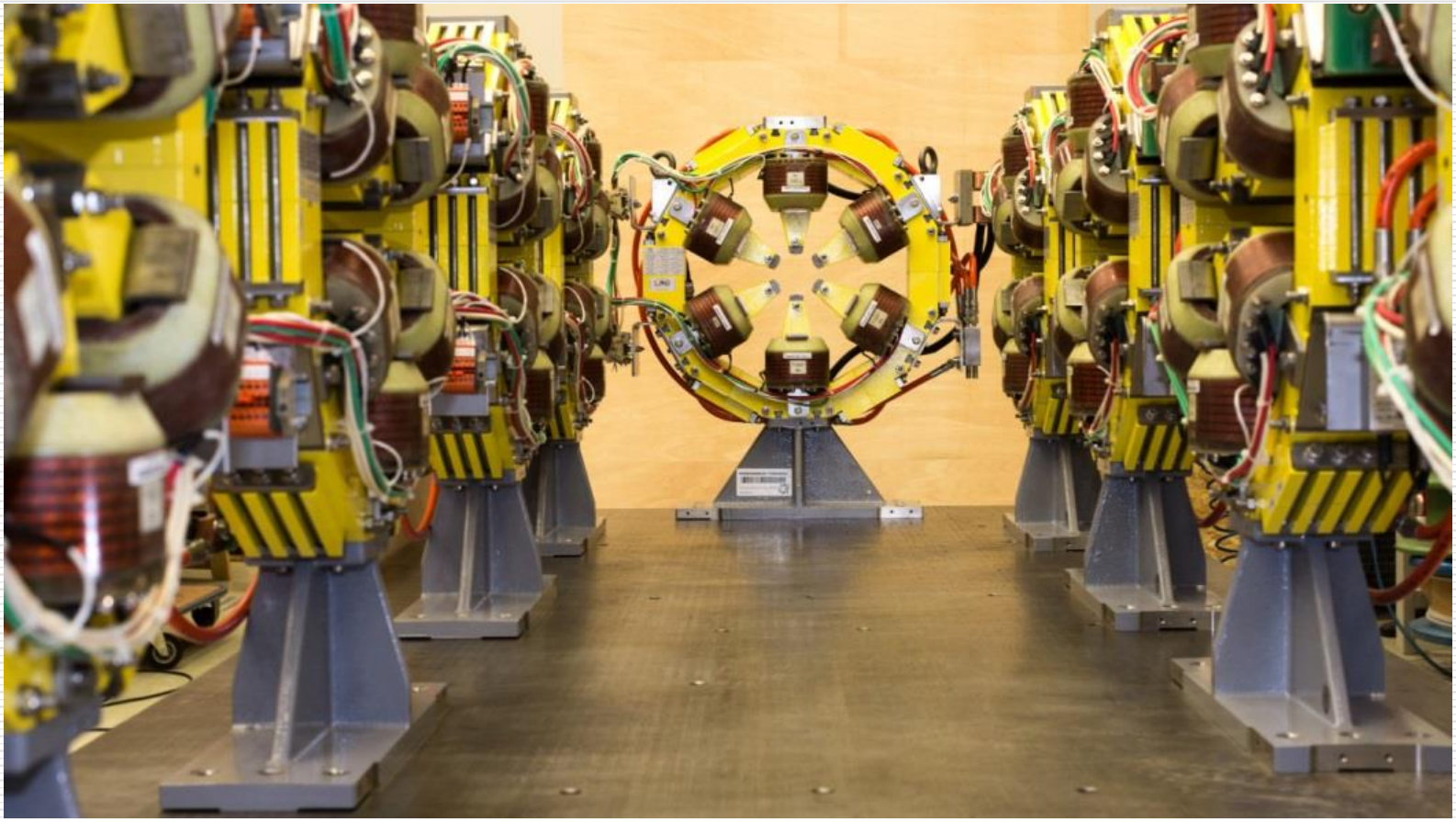
ARCA: Astronomy Research

→Astroparticle Physics currently coordinated at CERN

Full Partner → now Observer (waiting to sign MoU)

...also, some activation of Cyprus Industry

CNE Technology LtD. (2012-2016)



Sextpole Magnets for the SESAME Project

accurate, quality systems constructed in Nicosia

CMS Experiment at LHC

Contributions of UCY-HEP (2016-2020)

- **Search** for $H^{\pm} \to \tau^{\pm}\nu(\tau \to h)$ where $m_{H^{\pm}} \leq 160\ GeV/c^2$
- **Search** for light CP-even NMSSM higgs: $h^0 \to a^0 a^0 \to 4\tau, 4b, 2\tau 2b$
- **Measurement** of the $ZZ \to 4\mu$ production cross section
- **Single top** production and tagging using electrons

  Goal: gain expertise on lepton ids (e, μ, τ), tracking, b-tagging
- **Search for SM Higgs** H→γγ (simulation & ECAL resolution improvement algorithms)
- **Search for additional Higgs** under the **2HDM+S** model

  $h(125) \to aa \to 2b2\tau$ and $h(125) \to aa \to 2\mu 2\tau$

  $H^{\pm} \to tb$ with fully hadronic final state

  $A \to Zh \to l^+l^-(\nu\bar{\nu})b\bar{b}$

CMS Experiment at LHC

Contributions of UCY-HEP (2016-2020)

- **Physics analysis:**

Four new PhDs awarded based on 2016 data, $\sqrt{s}$= 13 TeV :

(1) Search for charged Higgs boson pp→H±(b)t M. Ather

(2) Search for the exotic decay H→α α → μμττ E. Erodotou

(3) Search for the exotic decay H→α α → bbττ D. Tsiakkouri

(4) Searches for signature of a heavy pseudoscalar A boson in the Two Higgs Doublet Model E. Ioannou

- **Work on the CMS trigger:**

Work on Level 1 trigger of CMS for HL-LHC to cope with the big increase in # of minimum bias events per beam crossing

Two new PhD Theses coming

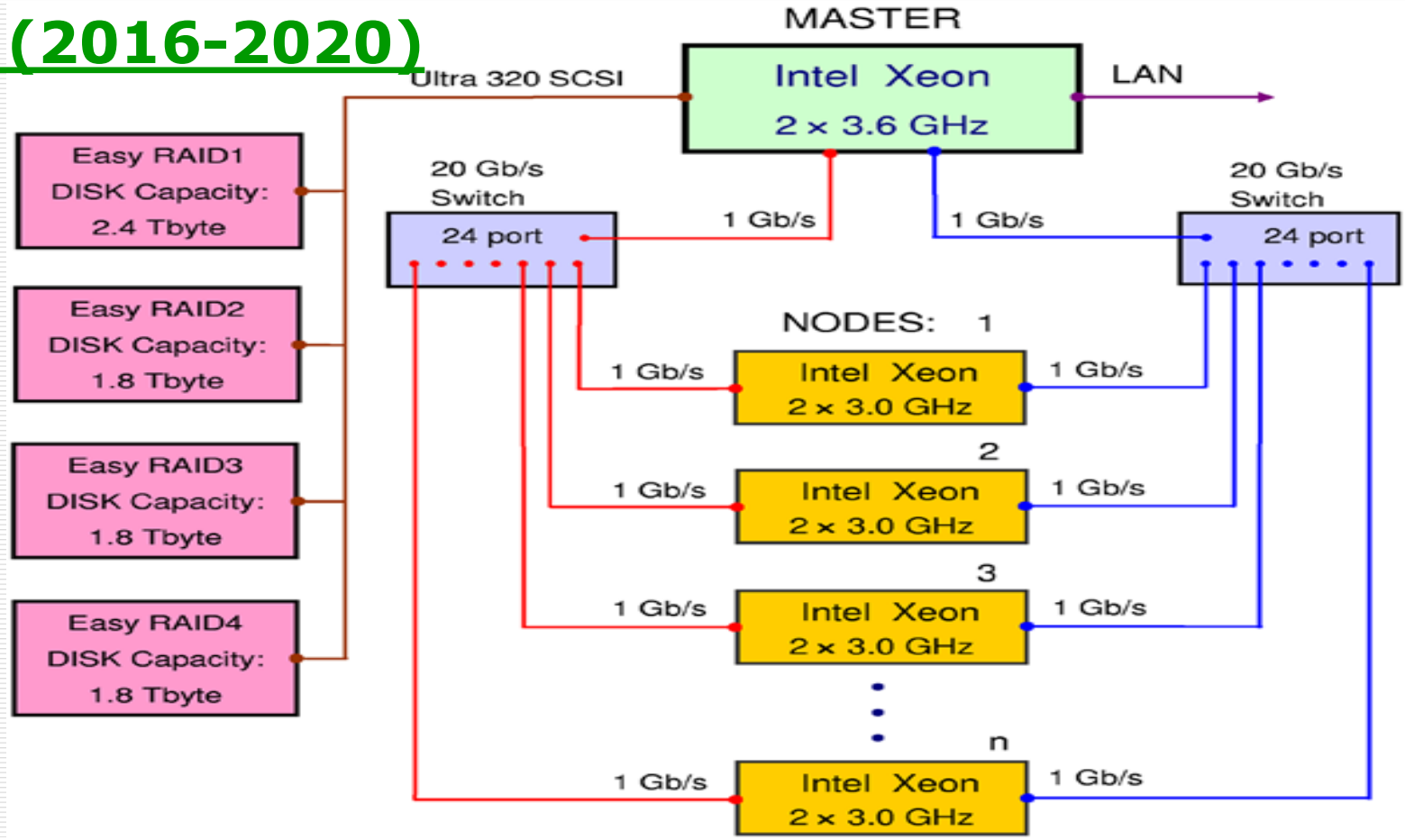
- **Radiation Dosimetry:**

Radiation Monitoring, Safety and Coordination in Point 5

Dr. E. Dimovasili (#2 Expert)

High-Performance Computing

UCY-HEP (2016-2020)



MAIN FEATURES

3 master/128 slave nodes, 616 cores – another **400** cores

Gigabit Ethernet network, inter-processor communications, nodes 2x1Gbps

Modularity, expandability, data transfer, storage and analysis

Total Disk Capacity 39 TB

Perspectives for the Future (2021-)

(1.) Upgrade of CMS for the HL-LHC phase

- **High Granularity Calorimeter upgrade:** PENDING

  Develop stations for testing readout electronics & power supplies

  Work on flexible electronics, integrated circuits, rad hard materials

  Trigger upgrade:

  Work on Level 1 trigger algorithms and simulation RUNNING

- **Data testing:**

  Stations for remote monitoring of data quality UNDER DEVELOPMENT

(2.) LHC phenomenology and CMS Analysis

- **Searches for Dark Matter and additional Higgs bosons**

  Expand on running experimental projects UNDER DEVELOPMENT

(3.) Education Program

- **Virtual visits at CERN**

  Development of Distance Learning programme PENDING

- **Host CERN Schools, Conferences and Workshops**

  Accelerator School, Analysis Workshops PENDING

- **IPPOG (signature pending ~1000 euro/year)**

  Masterclass program for high-school students RUNNING

Perspectives for the Future (2021-

(4.) Medical Physics Collaboration with CERN

- **HERMES Network (Greece, Cyprus, CERN):**
  Universities, medical centers, companies, fellowships — DEVELOPED
- **Development of better detectors:**
  Crystals, SiPMs and detectors with better resolution — NEW PHASE
- **Cyclotron Center for radiopharmaceuticals & diagnosis:**
  Promotion of Business Plan, PET scanning — DEVELOPED
  Implementation of construction, funding — PENDING
- **Cyclotron Center for Proton Therapy**
  Hadron therapy, radiation oncology, FLASH therapy — UNDER DEVELOPMENT
  Implementation of construction, funding — PENDING
- **KT Forum at CERN on Medical Applications** — RUNNING
- **Collaboration with Bank of Cyprus Oncology Center** — RUNNING

(5.) Collaboration on Data Science

- **Develop program on AI & Deep Learning:** — UNDER DEVELOPMENT

Problems and Solutions

Problems

1. Lack of critical mass of researchers in most fields
2. Insufficient PhD fellowships
3. Moderate infrastructure–lack of hardware & machine shops
4. Difficulties to activate industry and high-tech companies
5. Need clearly expressed research strategy
6. Need more support for young researchers
7. Brain drain
8. Lack of venture capital organizations
9. Need more flexibility and less paperwork

Proposed Solutions → **Quite URGENT to do**

1. Create strategic axis in RIF for funding CERN programs
2. Introduce PhD fellowships at sufficient level (universities, RIF programs, IKYK, other Organizations)
3. Attract engineers, physicists, material and computer scientists to formulate critical mass in CERN projects
4. Provide incentives to industry and SMEs to participate in CERN tenders and support researchers
5. Reduce unnecessary paperwork

Important Elements to follow-up

1. Strong programs and opportunities to attract researchers
2. Many of our talented students pursue careers abroad, in established universities, or employed as fellows at CERN
3. Managed to establish Research Fellow positions and other staff positions for Cyprus people at CERN
4. Technical Protocols and MoUs of Cooperation with CERN in Physics, Computing, Engineering, Radiation Physics and Education
5. Joint organization of CERN Summer Schools, workshops and international conferences
6. Potential for developing applications: detectors, DAQ electronics, run time monitoring & control systems, Grid computing, medical physics

Conclusions

(a) Strong collaboration with CERN for many years

(b) Technical Protocols signed between Cyprus and CERN in the fields of Physics, Computer Science, Health & Radiation

(c) UCY-HEP Group established strong involvement in international research projects

(d) Strong expertise in the analysis of the Standard Model & in the searches for new physics, particles and phenomena

(e) Great potential for improvement in several application areas: detectors, electronics, monitoring & control systems, grid computing, simulation, dosimetry & radiation physics

(f) Many activities will benefit further by increasing the funding & manpower of the Cyprus research groups

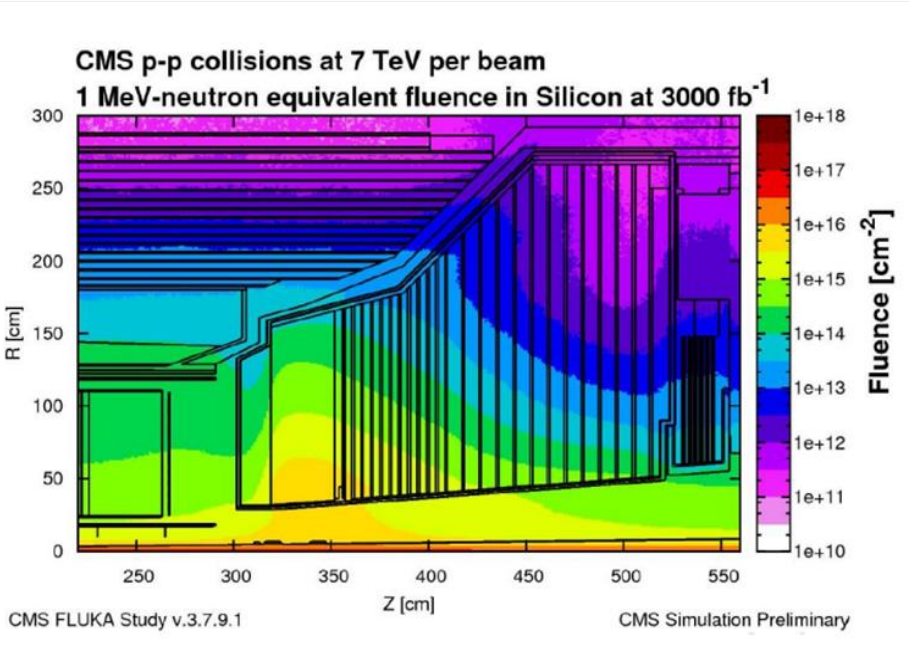
(g) Cyprus industry & high-tech companies will increase their productivity/competitiveness in the international environment

(h) Colleagues from many scientific fields are invited to join.

Promote CERN in Cyprus and Cyprus @ CERN

BACKUP MATERIAL

Radiation damage of Endcap Calorimeter



Neutron fluence equivalence vs Z and R

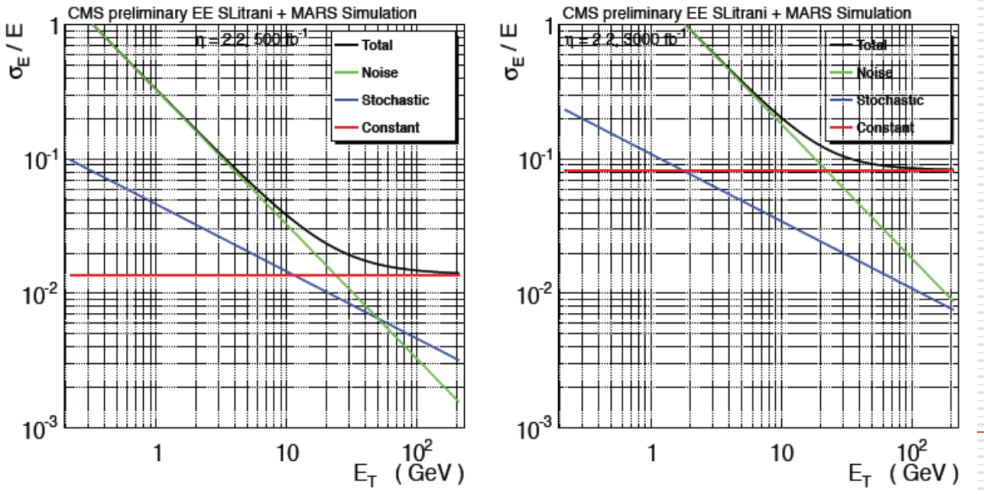
HL-LHC Program:

Higher CM Energies

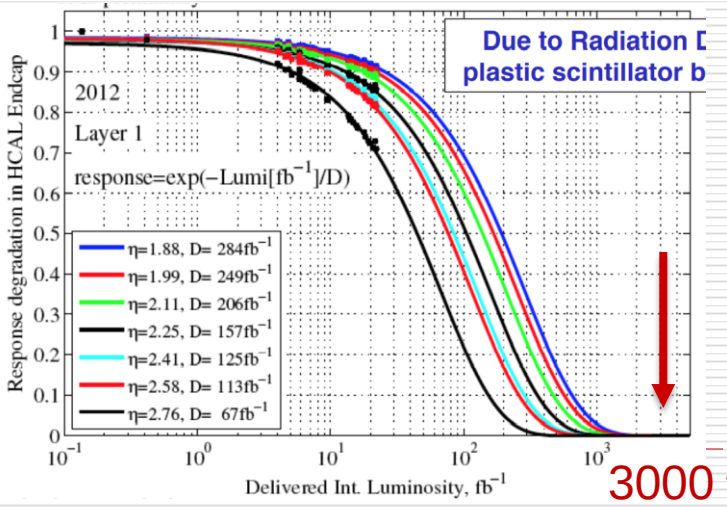
Higher Luminosities $5 \times 10^{34} - 2 \times 10^{35}$ cm^{-2} s^{-1}

25 ns beam cross rate

140-200 pileup events per beam crossing



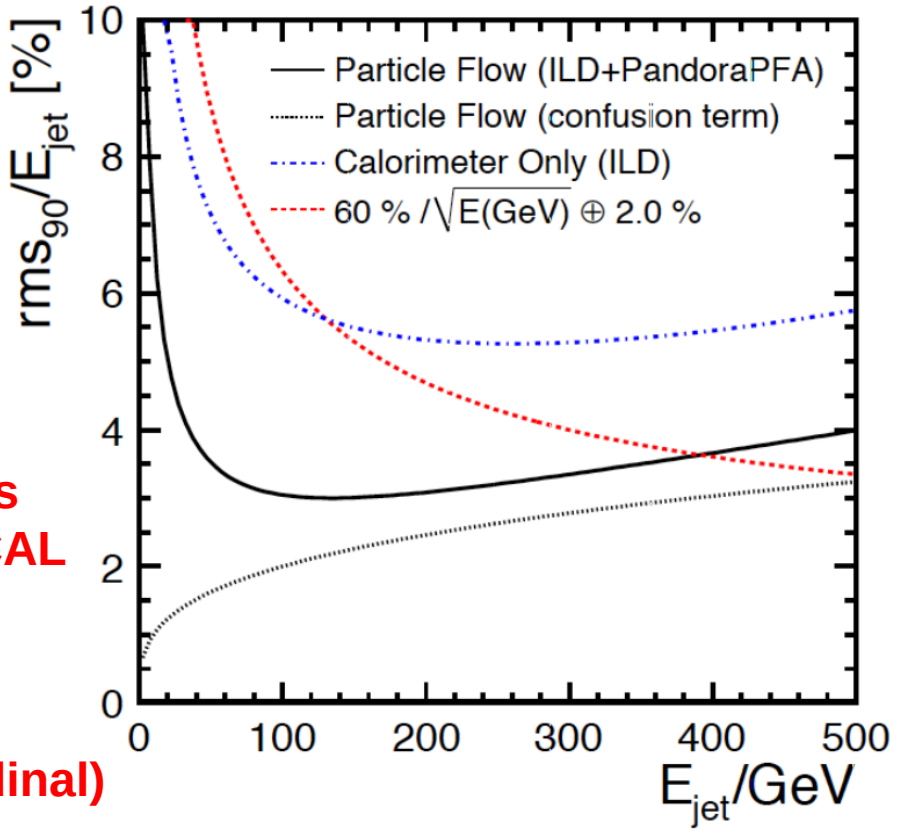
EE degradation at 500 fb^{-1} vs 3000 fb^{-1}



HCAL radiation damage of plastic scintillator

Particle Flow Resolution vs Calorimeter Clusters

At higher energies jets are narrower.
Particle Flow algorithms, combined with high granularity provide better resolution than energy cluster reconstruction alone



SEARCH FOR:

- **Radiation hard detector and electronics**
- **Very good energy resolution ECAL+HCAL (high density, small Moliere Radius)**
- **Good Particle ID & shower separation**
- **Precision timing capability**
- **High granularity (transverse & longitudinal)**
- **Pileup rejection**

→ **Silicon** sampling Calorimeter at high radiation area and **scintillator** material read by **SiPMs** in lower radiation area, combined with **W, Pb Cu & stainless-steel** as absorber is the optimum solution.

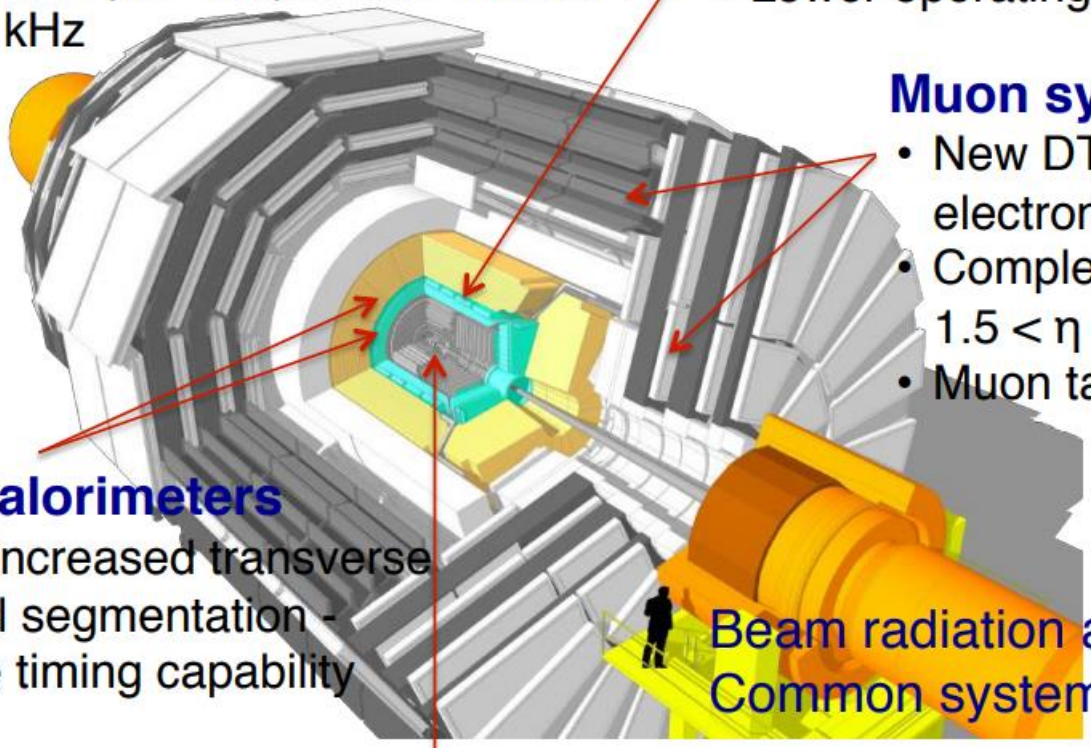
CMS Upgrade for HL-LHC

Trigger/HLT/DAQ

- Track information in Trigger (hardware)
- Trigger latency 12.5 μs - output rate 750 kHz
- HLT output 7.5 kHz

Barrel EM calorimeter

- New FE/BE electronics
- Lower operating temperature (8◦)



Muon systems

- New DT & CSC FE/BE electronics
- Complete RPC coverage $1.5 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

New Endcap Calorimeters

- Rad. tolerant - increased transverse and longitudinal segmentation - intrinsic precise timing capability

Beam radiation and luminosity
Common systems &infrastructure

New Tracker

- Rad. tolerant - increased granularity - lighter
- 40 MHz selective readout (Pt≥2 GeV) in Outer Tracker for Trigger
- Extended coverage to $\eta \approx 3.8$

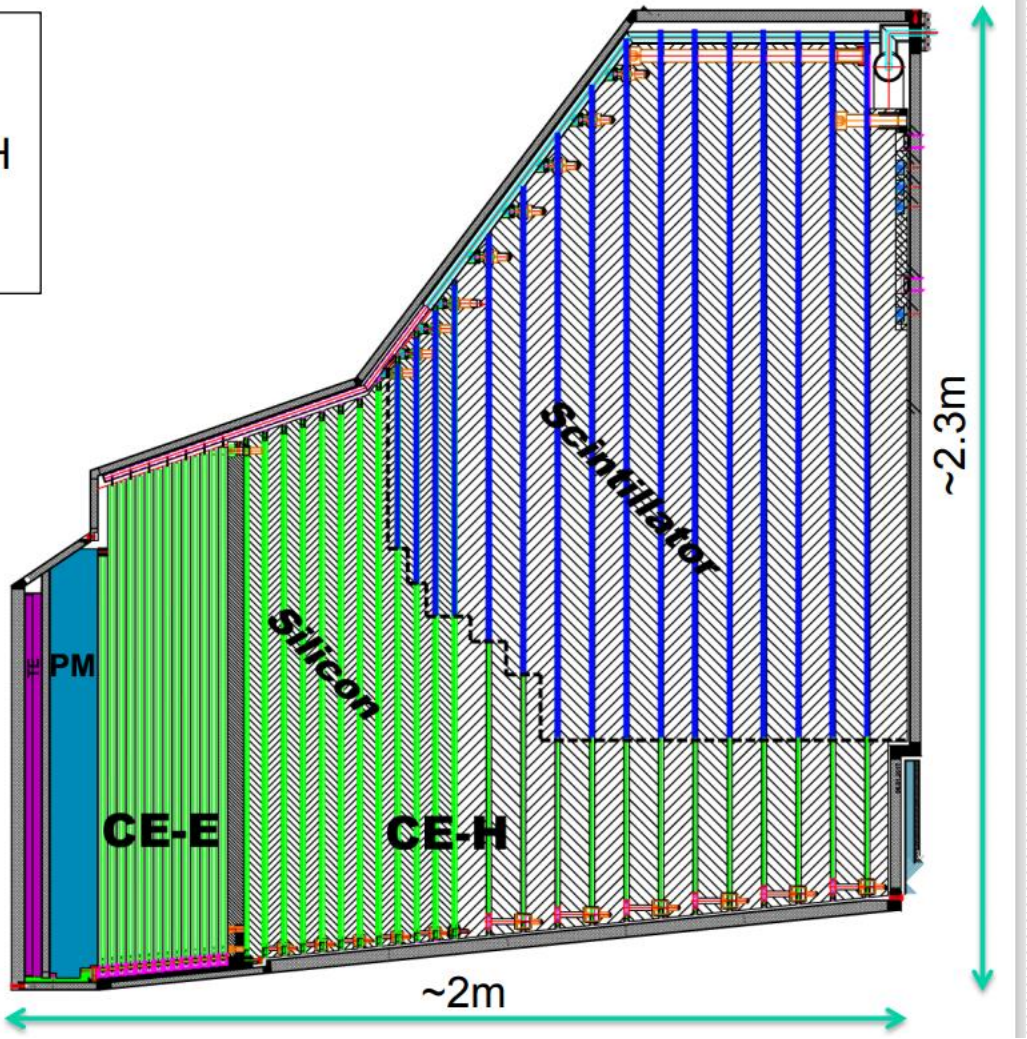
HGCal geometry & specs

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:

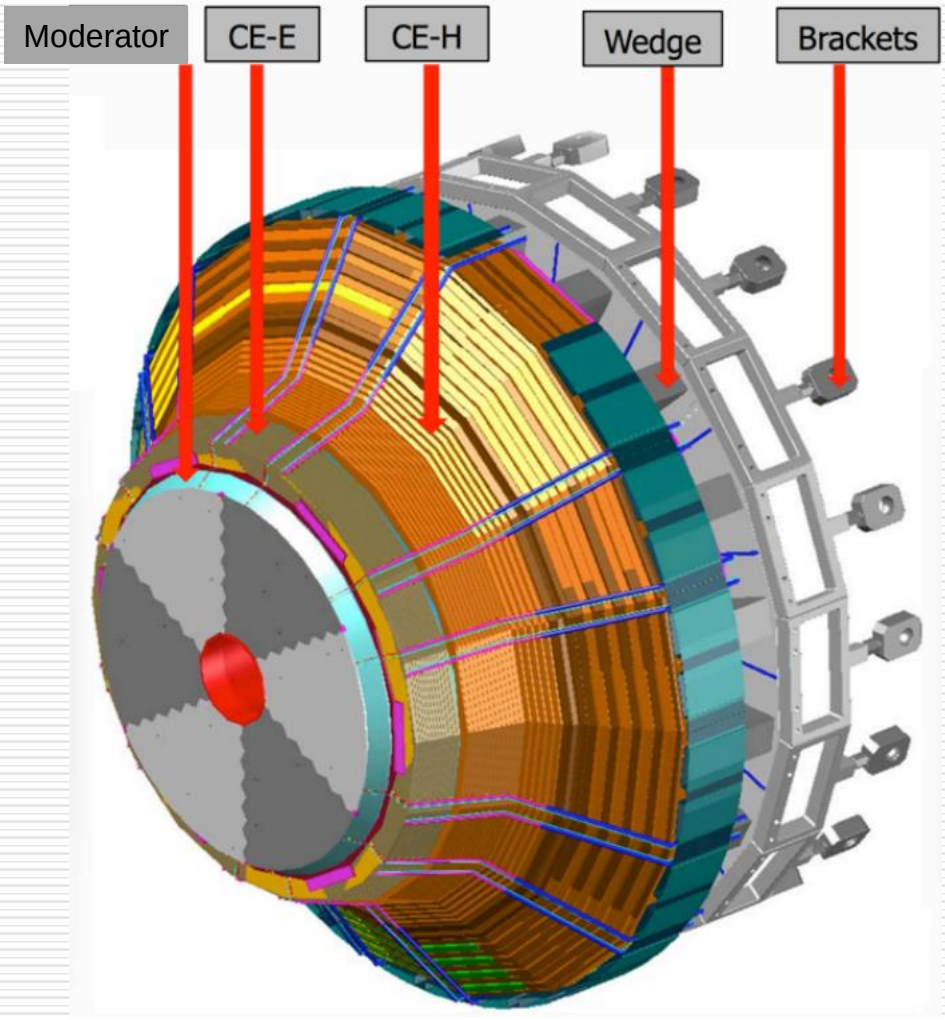
- HGCAL covers $1.5 < \eta < 3.0$
- **Full system maintained at -30°C**
- **~600m²** of silicon sensors
- **~500m²** of scintillators
- 6M Si channels, 0.5 or 1.1 cm² cell size
  - Data readout from all layers
  - Trigger readout from alternate layers in CE-E and all layers in CE-H
- ~27000 Si modules



EM Calorimeter (CE-E): Si, Cu/CuW/Pb absorbers, 28 layers, 26 X_0 & ~1.7 λ

Hadron Calorimeter (CE-H): Si & Scintillator, steel absorbers, 24 layers, 9.0 λ

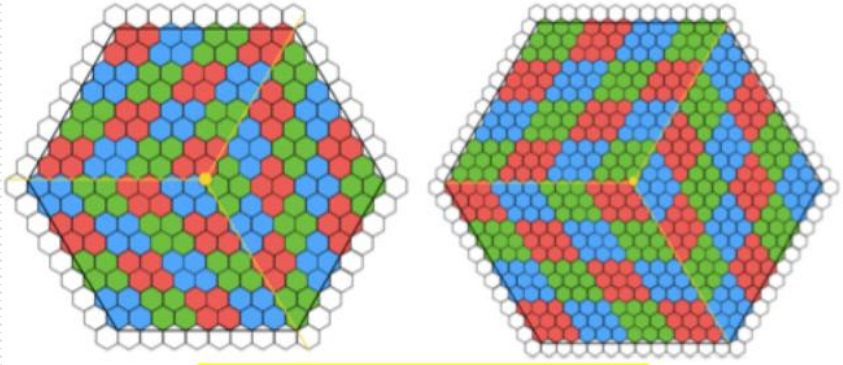
New Endcap Calorimeter



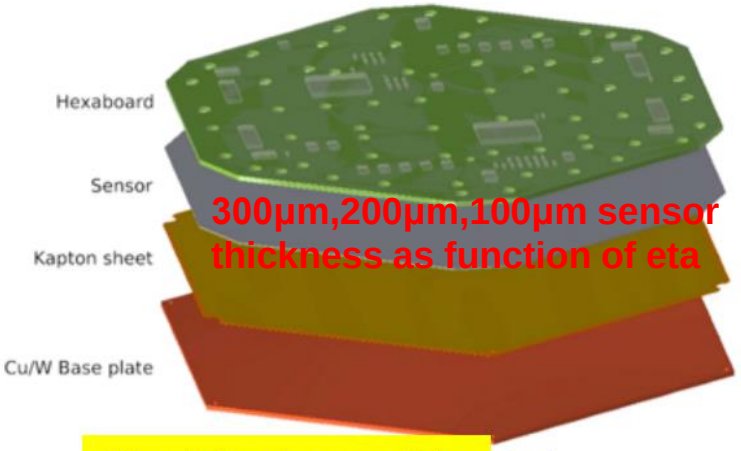
Many environmental and other monitoring sensors, gas and fluid supplies, thermal shield, power supply modules etc.

Hexagonal Si sensors' geometry

8inch, 1.18cm^2(192) / 0.52cm^2(432)

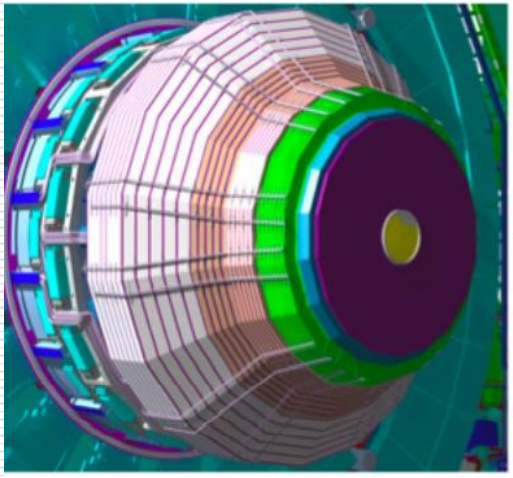


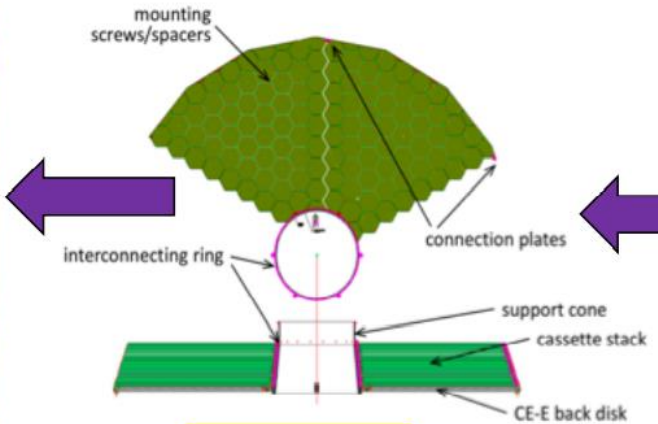
Sensors (Hexagon)



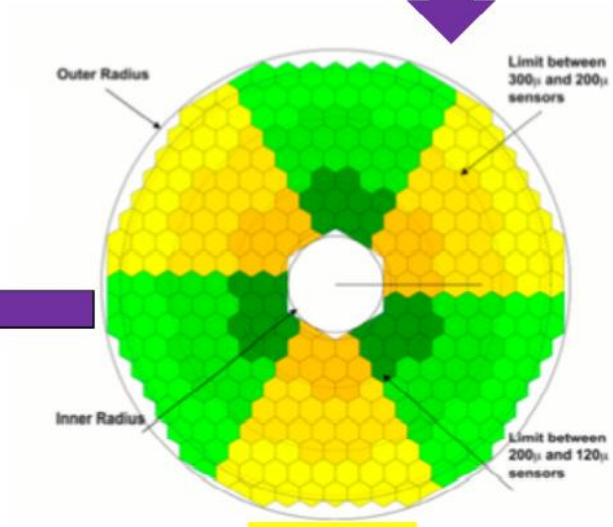
Module Assembly

300µm, 200µm, 120µm sensor thickness as a function of eta



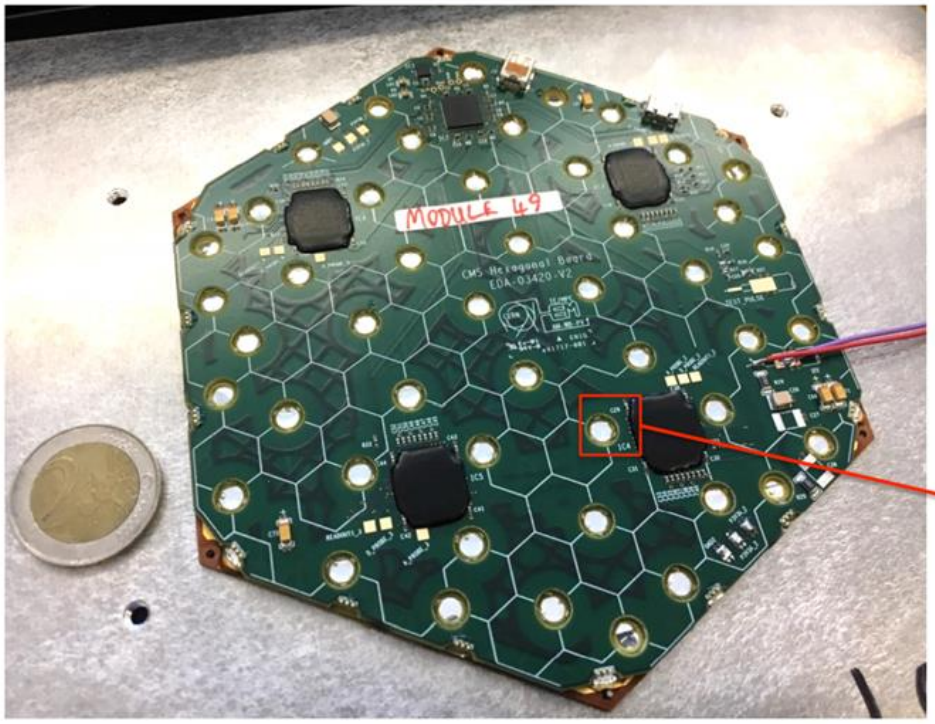


Stacking

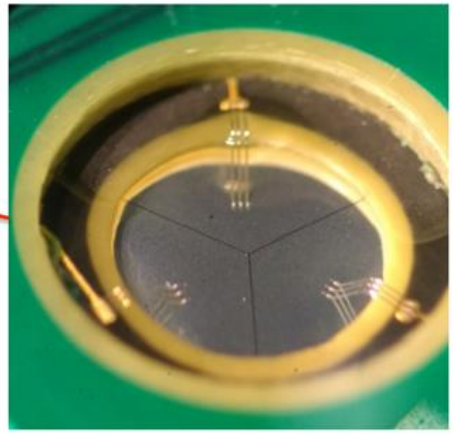


Tiling

Modules with double side cassettes

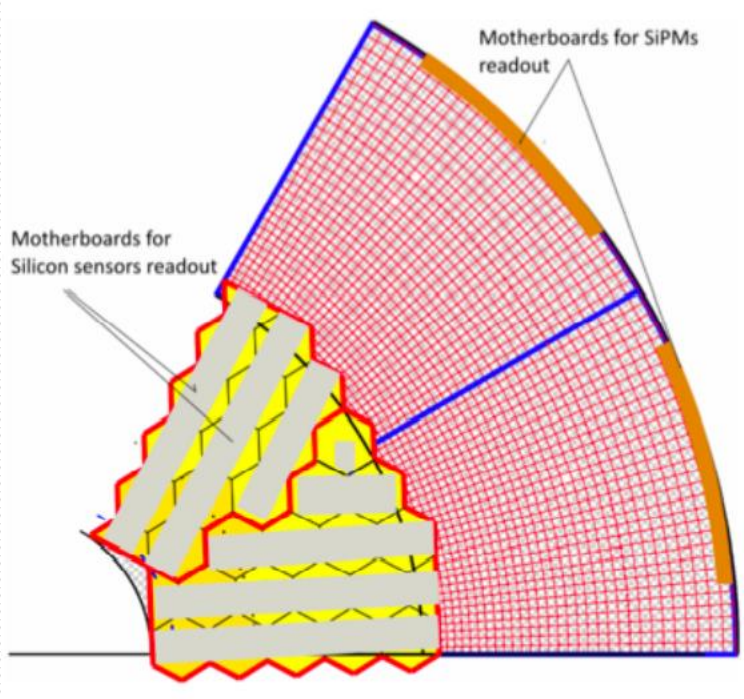


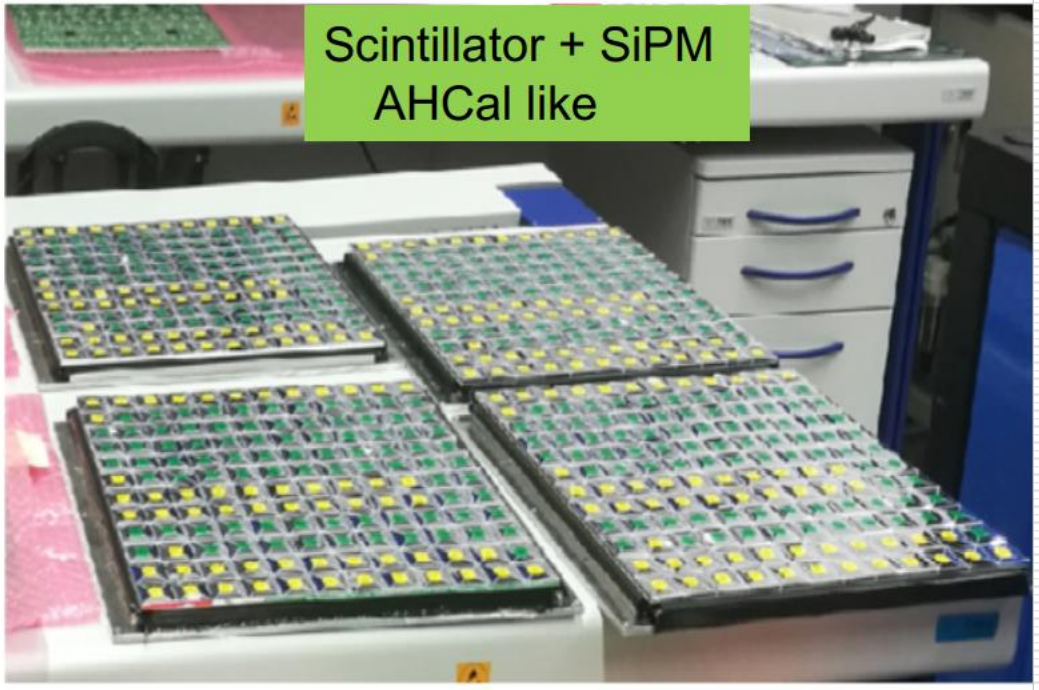
Wire bonding from PCB to silicon through holes



Module layer mounted on Cu cooling plate to form 30^0 Cassettes.
In EE Cassettes are double sided, in FH single sided.
Cassettes are inserted into carbon-fibre alveolar structure.

Geometry





ECAL (CE-E)

28 Layers Si + W/Pb/Cu

25 X0 & ~1.3 λ

HCAL (CE-H)

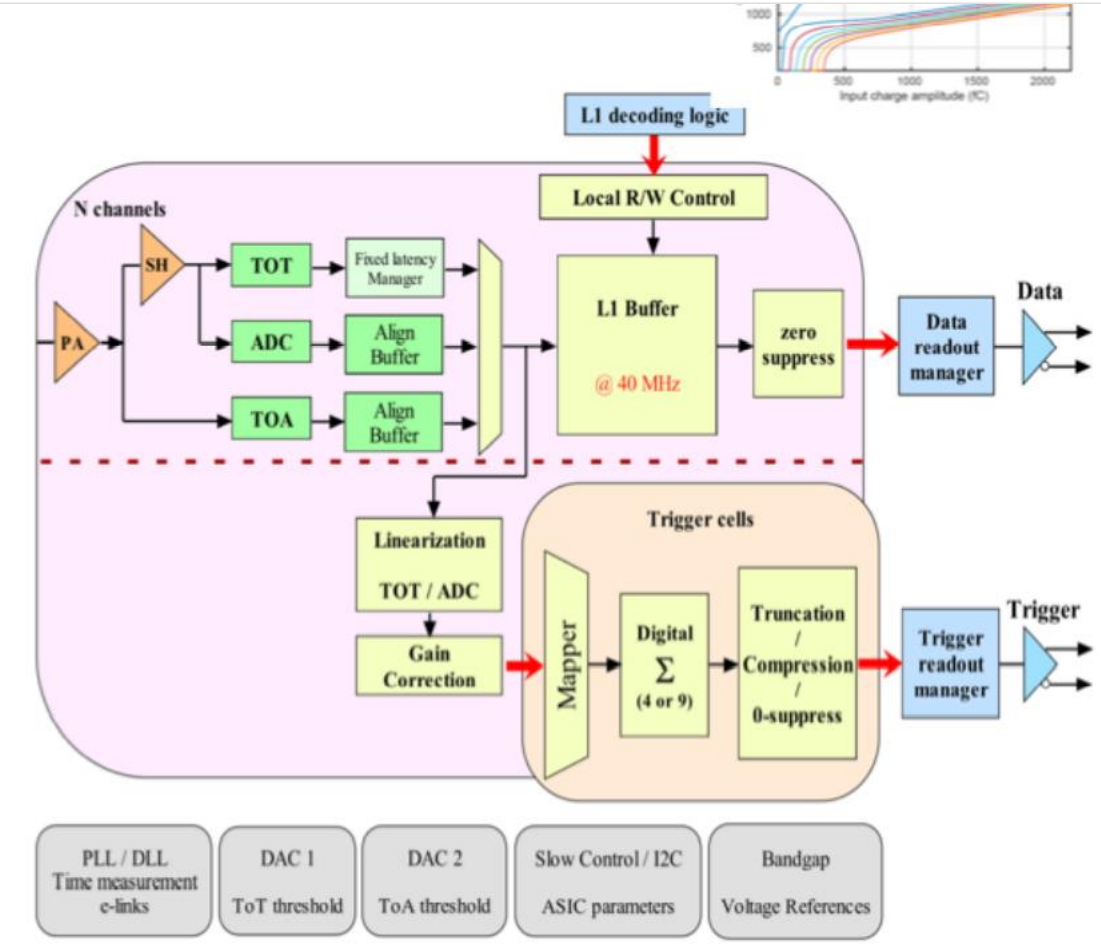
24 Layers Si/Scintillator + stainless steel

~8.5 λ

Front-End Electronics
HGCal on-detector control and readout

Requirements (not a full list)

- Radiation hard (of course)
- Low noise: <2500e
  - Including sensor leakage current noise
- Shape time: <20 ns
  - Sensor pulse Shape is 1-2 ns
- Dynamic Range 0.2fC -10 pC
  - High gain for < 100 fC
  - ToT for ~100 fC – 10 pC
- Low power: ~20 mW/channel
  - total ~ 100kW for 6M channels
- <100 ps time resolution per cell



Front-End chip with large dynamic range (up to 10pc, with 3000 MIP for 300 µm thick sensors), low noise, low power (10 mW per channel), connected to pre-amplifier/shaper, 10bits ADC, TDC with time precision 50ps.