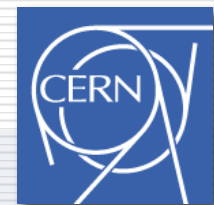




RECFA Members

Welcome to Cyprus



Contribution of Cyprus to the Scientific Program of CERN

Panos 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**
- Technical Protocols **Cyprus-CERN**
- Future Activities and Plans
- Research Funding and Problems
- Elements to follow-up
- Conclusions

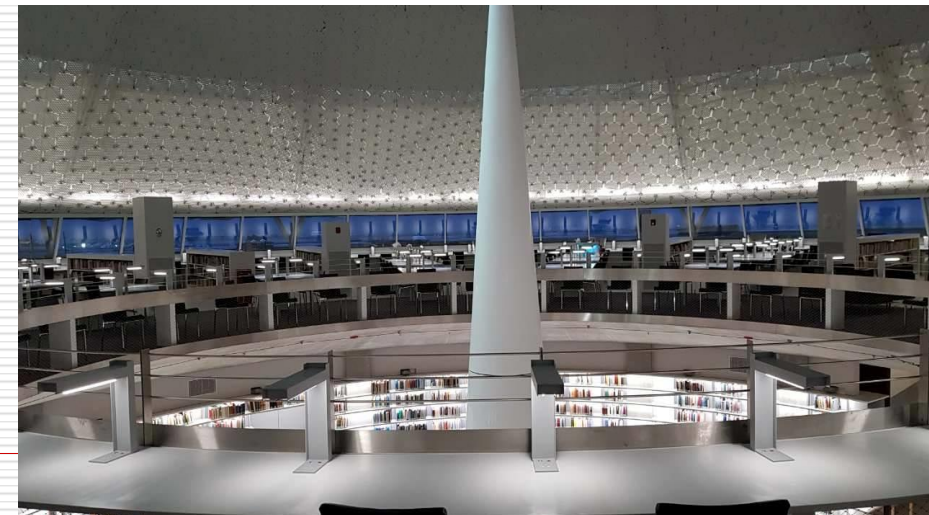
Introducing Cyprus



Introducing Cyprus



University of Cyprus Campus



Introduction

State Universities

University of Cyprus (1992) -----> collaborating with CERN

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)

Research Institutes

Agricultural Research Institute (1962)

State General Laboratory (1970)

The Cyprus Institute of Neurology & Genetics (1990)

The Cyprus Institute (2005)



Introduction

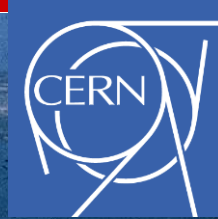


University of Cyprus: Physics BSc (1993), MSc & PhD (1999)
UCY- HEP Group: founded in 1992

PROJECTS	STATUS
L3 Experiment at LEP	Completed (analysis, monitoring, data taking)
CDF Experiment at FNAL	Completed (analysis, calibration, data taking)
CMS Experiment at LHC	Running (construction, monitoring, data taking, analysis, trigger)
E/M Fields (ΕΠΕΦ)	Non-Ionizing Rad (data taking/analysis)
KM3NeT (ESFRI)	Neutrino Telescope (ORCA & ARCA) TDR completed, project launching
High Performance Computer Cluster	Large Data Handling (processing & analysis)
Active Dosimeters (ESA)	Development of active dosimeters, simulation of radiation dosimetry & radiation damage
COST Action FAST (EU)	Fast Advanced Scintillator Timing (new systems with picosec response)

European Organization for Nuclear Research

Lac Lemman
Genève



SCIENCE

Research

Education

Geneva

CERN

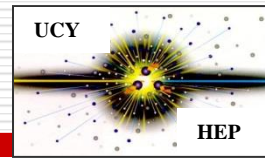
Technology

Discoveries

Collaboration

History of Cyprus - CERN

- 1986, October 1:** Joined the L3 Experiment at LEP, CERN
- 1992, September 7:** High Energy Physics Laboratory founded
- 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:** Official Non Member State Status
- 2009, June 5:** Application for a Member State
- 2012, October 5:** Signature to become Associate Member State
- 2016, April 1:** Cyprus Associate Member State of CERN in pre-stage to Membership



Current Members of the Group:

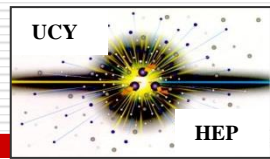
- **P. Razis** Professor
- **F. Ptochos** Associate Professor
- **H. Saka** Lecturer

- **J. Mousa** Research Associate
- **A. Attikis** Research Associate
- **E. Dimovasili** Postdoctoral Fellow
- **Hans Rykaczewski** Emeritus, Affiliated to Group

- **C. Nicolaou** MSc, Electronics Engineer
- **Dr. M. Constantinou** Computer Engineer



UCY-HEP Group



- **A. Papadakis** Assoc. Prof. (affiliated)
- **I. Parpottas** Assist. Prof. (joins Group)

- **E. Erodotou, D. Tsiakkouri,
W. Ather** PhD awarded recently
PhD awarded recently

- **E. Ioannou, M. Kolosova,
S. Constantinou, S. Pantelides,
C. Christoforou** PhD Students

- **M. Haraki, M. Toumazou
C. Leonidou** MSc awarded recently
Graduate Student (MSc)

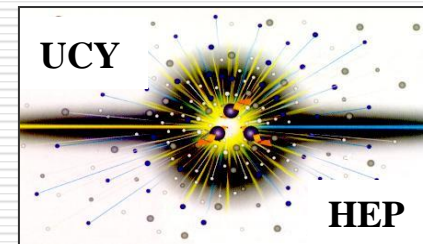
- **6 undergraduate students** Final Year Projects



UCY-HEP Group

Personnel so far of UCY- HEP Group

- **3 Faculty Staff**
- **10 Postdoctoral Fellows**
- **16 Research Assistants**
- **4 Honorary guest members**
- **15 PhD students**
- **3 Electronic Engineers**
- **15 MSc students**
- **55 Final Year Projects students**



Hosted 12 International Conferences:

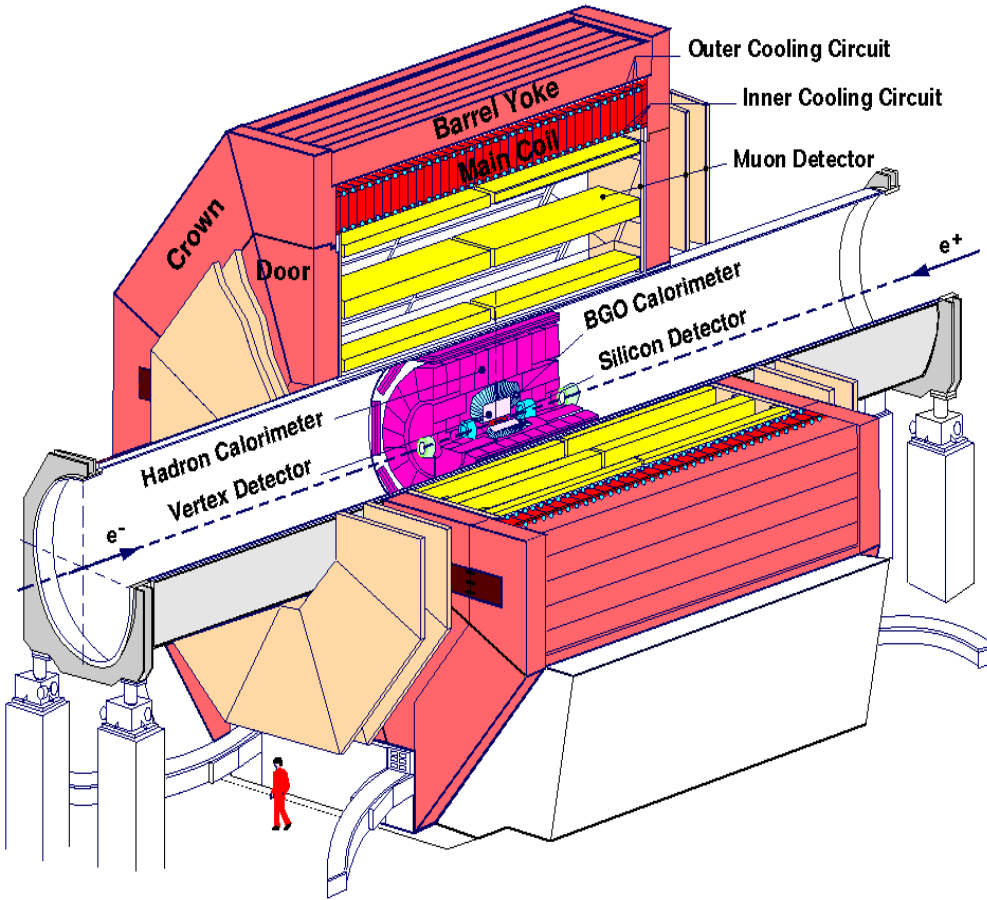
among these:

CMS Week 2008, 6/2008

CSC 2013, 8/2013

COST Action FAST, 3/2017

L3 Experiment (1989-2000)



$e^+ e^- \rightarrow \text{hadrons}$
 $E_{CM} = 90\text{-}209 \text{ GeV}$
 $L = \sim 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
 $B = 0.5 \text{ Tesla}$

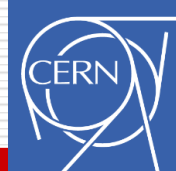


L3 Experiment

LEP tunnel



L3 Experiment (1989-2000)



Contributions of UCY-HEP

1. **Alignment of the L3 Muon Spectrometer (Laser Beacon)**
2. **Calibration of the L3 Muon Spectrometer (N₂ 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 on:

Z⁰ lineshape

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

search for excited leptons

search for MSSM higgs

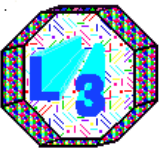
particle matching

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

search for Z'

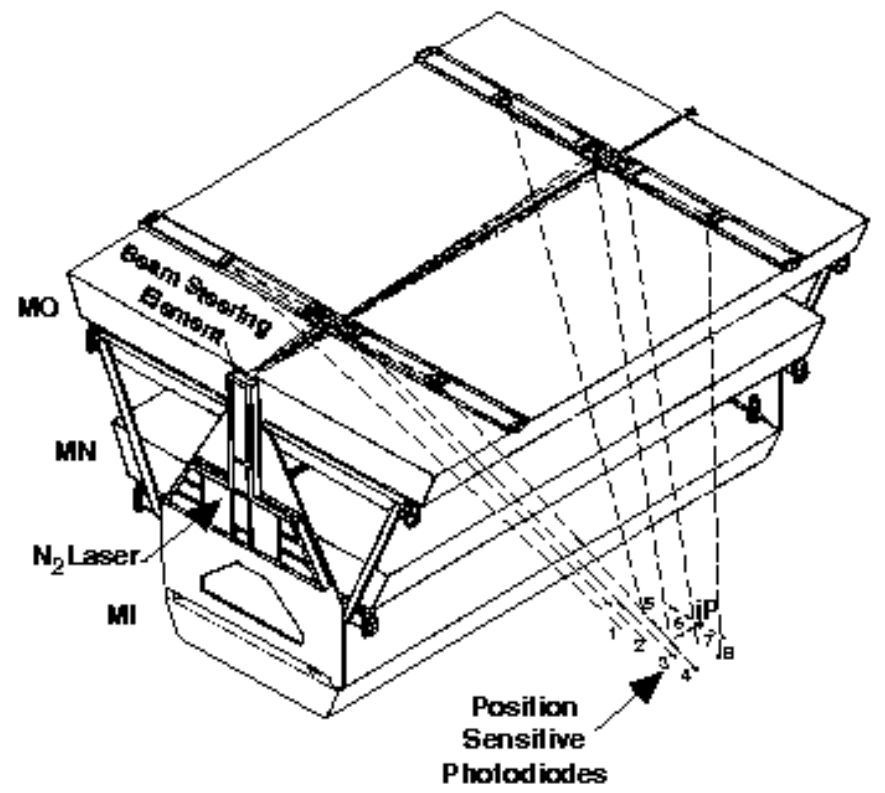
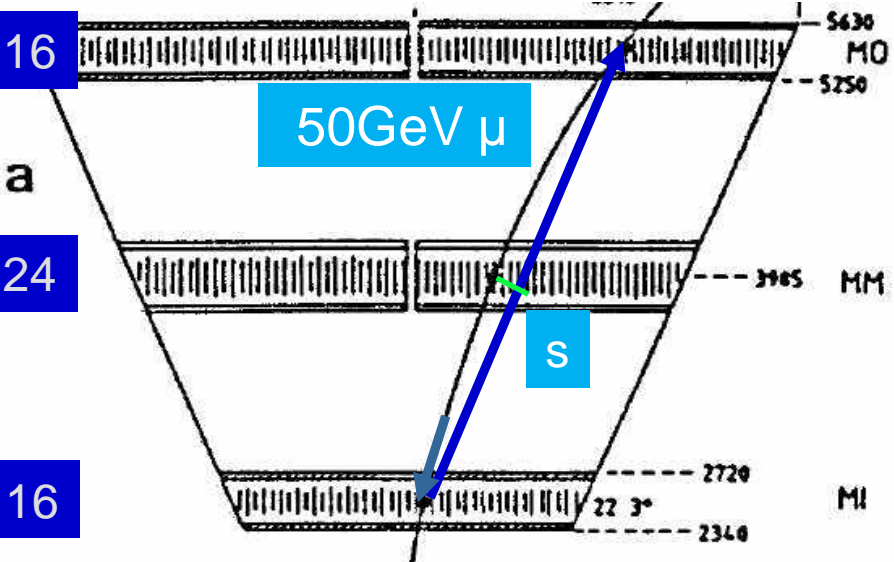
search for neutralino

L3 Muon Spectrometer



He-Ne Laser Beacon: Alignment

N2 Laser: Calibration of U_d



$$s = \frac{L^2}{8R} = \frac{0.30BL^2}{8P} = 3.4mm \quad \frac{\Delta s}{s} = \frac{\Delta P}{P} \approx 2.2\%$$

$$\Delta s = \Delta s_{cham} \oplus \Delta s_{mult.scatt.} \oplus \Delta s_{align.} \approx 75\mu m$$

48 μm 45 μm \Rightarrow ~30 μm

Laser light ionizes TMPD dopant
Simulation of infinite P_μ

Torsion measured to: $\pm 25\mu rad$ \Rightarrow $\pm 10\mu m$

Extreme Accuracies

L3 Results/Limits



(1) Contribution to the measurement of the Z^0 lineshape

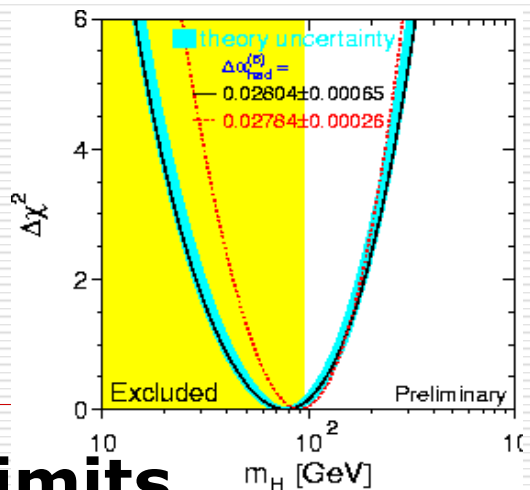
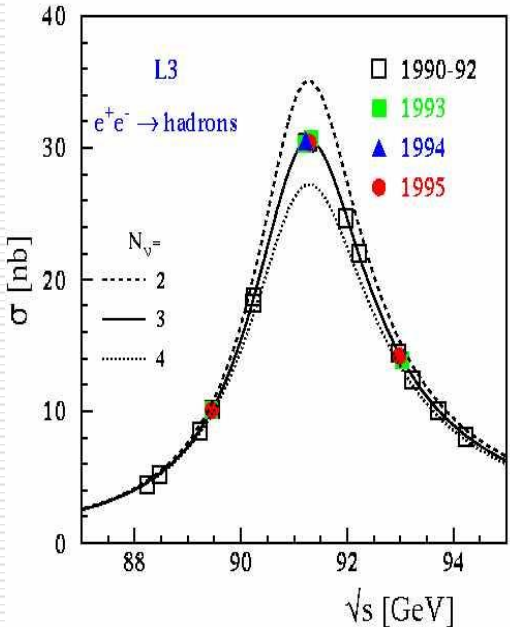
$M_Z = 91.1898 \pm 0.0031 \text{ GeV}$
 $\Gamma_Z = 2.5024 \pm 0.0042 \text{ GeV}$
 $N_V = 2.9840 \pm 0.0082 \text{ (LEP) indirectly}$
 $N_V = 2.98 \pm 0.05 \pm 0.04 \text{ (L3) directly}$

(2) Search for new particles

$M_H > 112 \text{ GeV}$	$M_H > 114.4 \text{ GeV}$
$M_h > 86.0 \text{ GeV}$ MSSM	$M_H = 129 + 74 - 49$
$M_A > 86.5 \text{ GeV}$	SM higgs
$M_{H^\pm} > 76.5 \text{ GeV}$	

(3) Search for excited particles

$m_{e^*} > 100.1 \text{ GeV}$	$m_{\nu e^*} > 99.3 \text{ GeV}$
$m_{\mu^*} > 100.3 \text{ GeV}$	$m_{\nu \mu^*} > 99.4 \text{ GeV}$
$m_{T^*} > 99.9 \text{ GeV}$	$m_{\nu T^*} > 93.9 \text{ GeV}$



Precise Measurements/Exclusion Limits



L3 Results/Limits

(4) Search for Supersymmetric Dark Matter

Neutralinos $X^0_1, X^0_2, X^0_3, X^0_4$

X^0_1 = Lightest Supersymmetric Particle

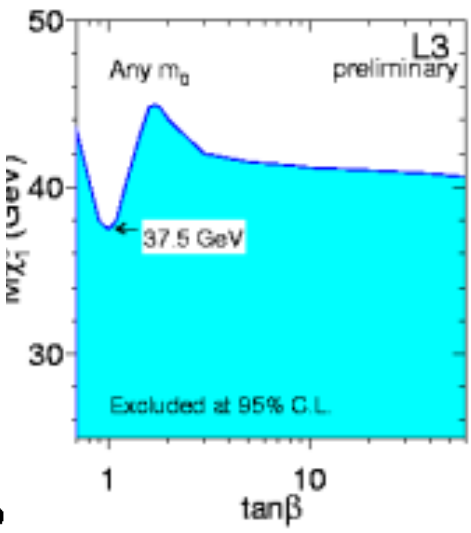
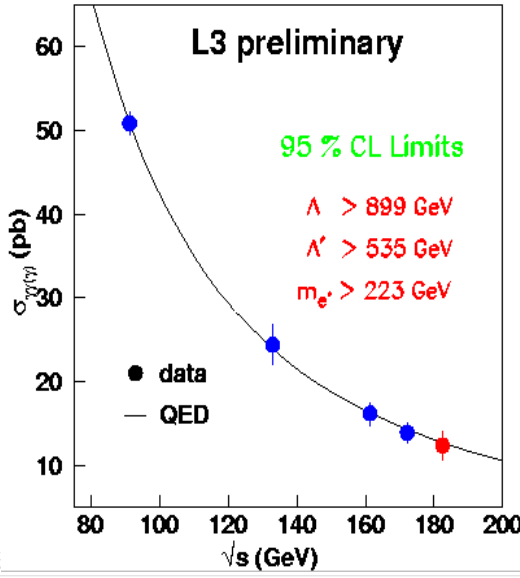
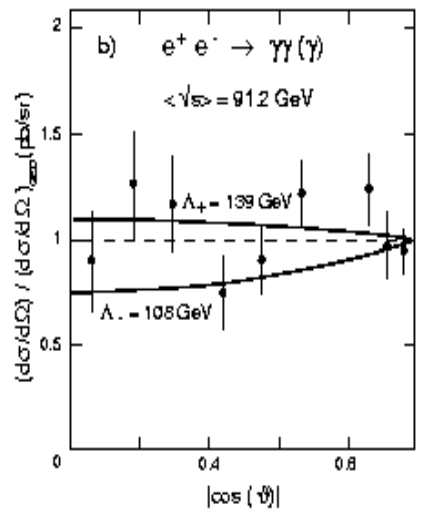
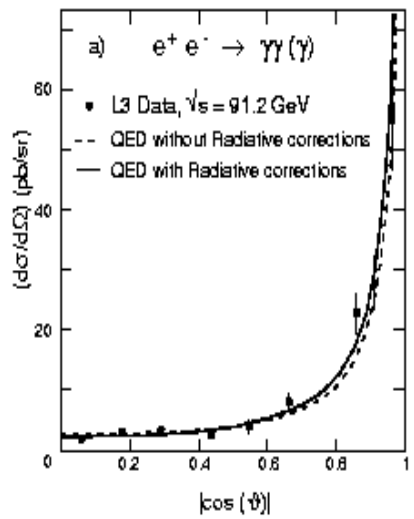
$m_{X^0_1} > 32.5 \text{ GeV}$ $\tan\beta > 0.7$

(5) Tests of QED / Rare Decays

$\text{Br}(Z \rightarrow \mu\tau) < 19 \times 10^{-6}$ $\text{Br}(Z \rightarrow \pi^0\gamma) < 5.2 \times 10^{-5}$

LFV $\text{Br}(Z \rightarrow e\tau) < 13 \times 10^{-6}$ $\text{Br}(Z \rightarrow \gamma\gamma) < 5.2 \times 10^{-5}$

$\text{Br}(Z \rightarrow e\mu) < 6 \times 10^{-6}$ $\text{Br}(Z \rightarrow \eta\gamma) < 7.6 \times 10^{-5}$



Precise Measurements/Exclusion Limits



LHC Program

CERN - LHC
27 km circumference

Lac Lemman
Genève

CMS

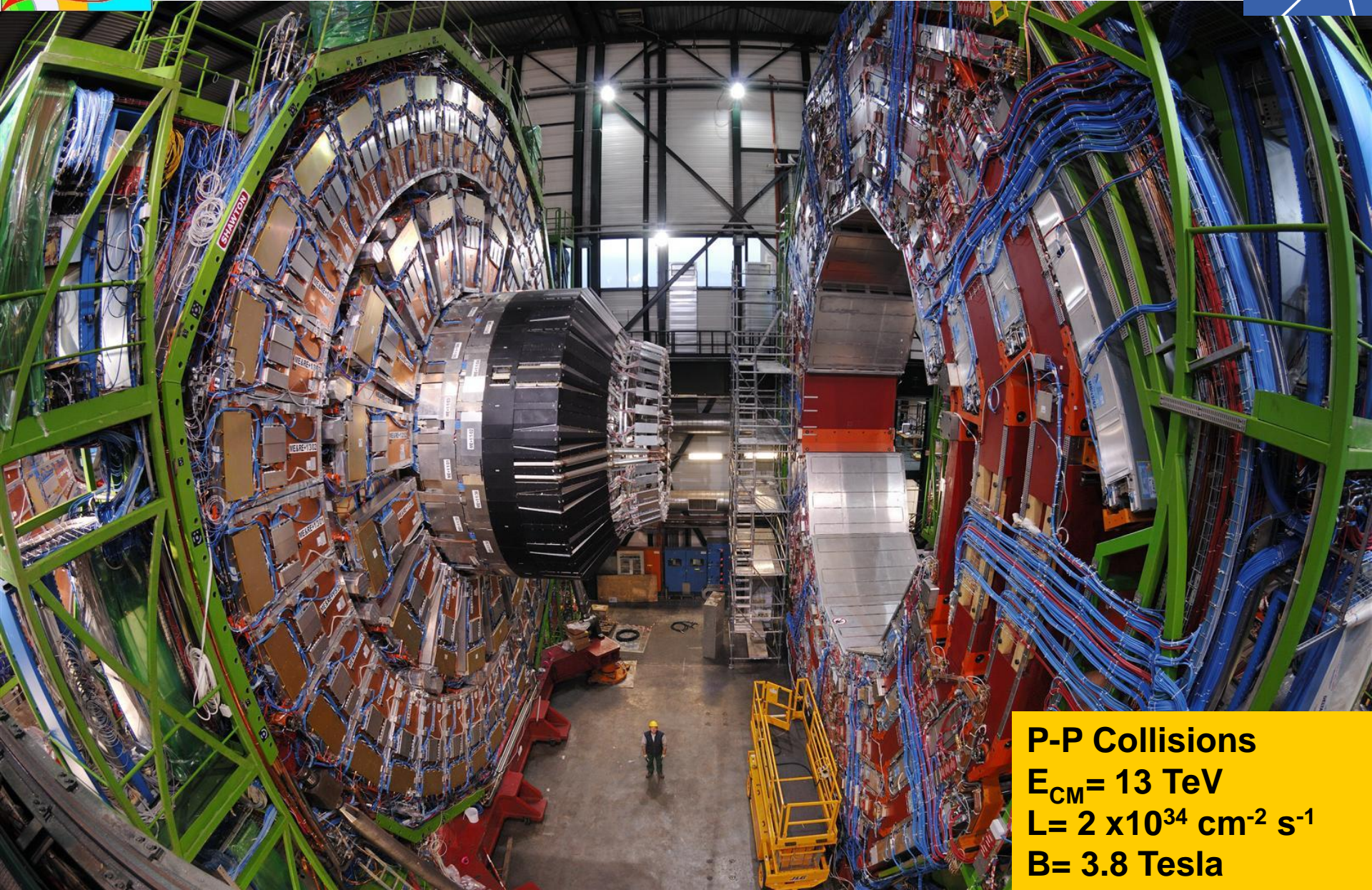
LHC

LHCb

ALICE

ATLAS

CMS Experiment (1995-today)



P-P Collisions
 $E_{\text{CM}} = 13 \text{ TeV}$
 $L = 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 $B = 3.8 \text{ Tesla}$

SUPERCONDUCTING COIL

CALORIMETERS

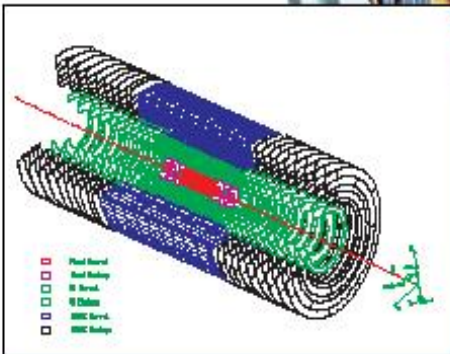
ECAL Scintillating $PbWO_4$ Crystals

HCAL Plastic scintillator copper sandwich

IRON YOKE

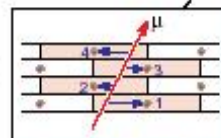
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

TRACKERS

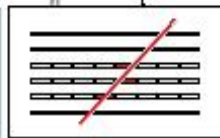


Micro Strip Gas Chambers (**MSGC**)
Silicon Microstrips
Pixels

MUON BARREL

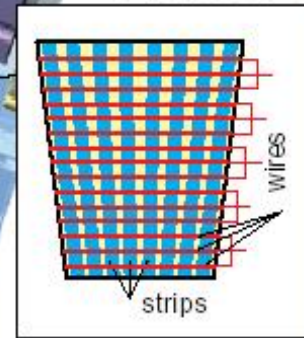


Drift Tube Chambers (**DT**)



Resistive Plate Chambers (**RPC**)

MUON ENDCAPS



Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

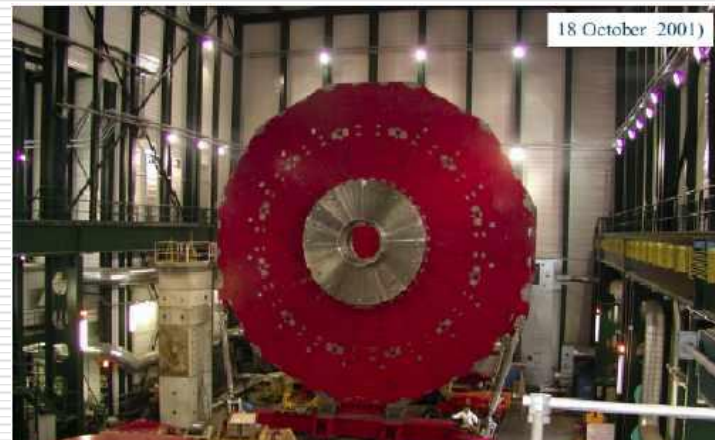
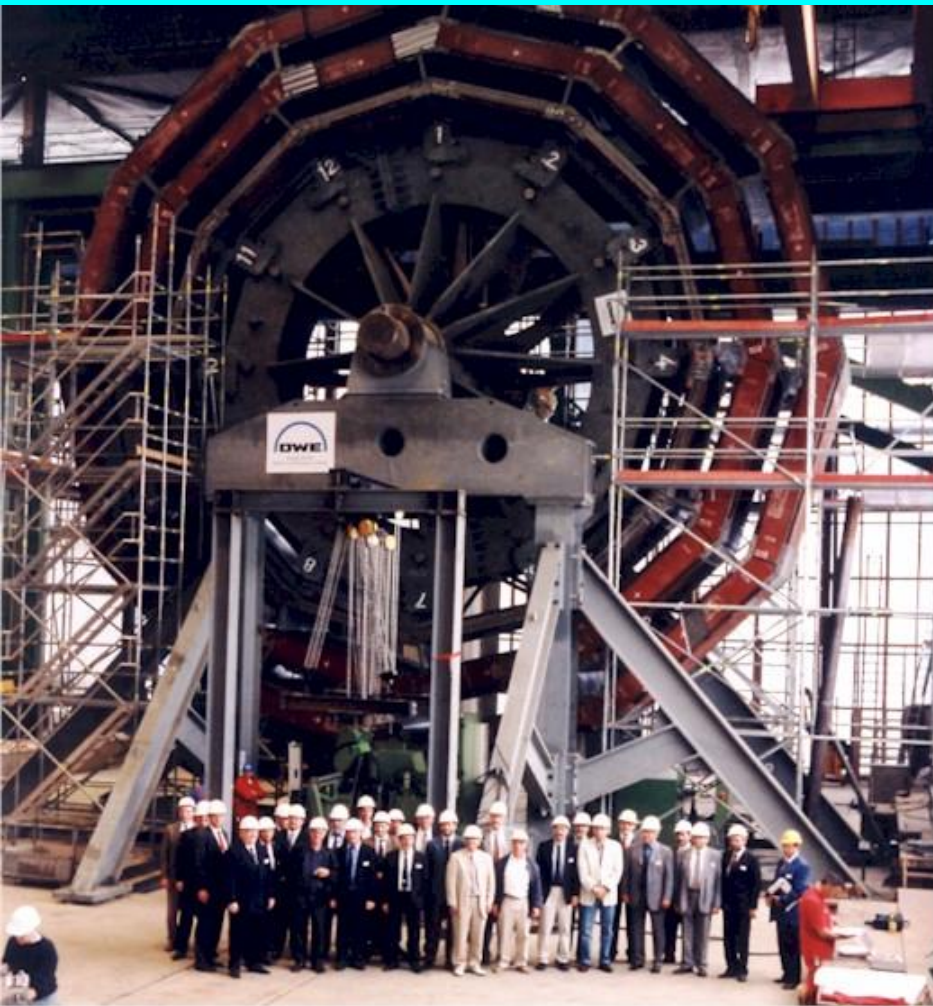


CMS Experiment

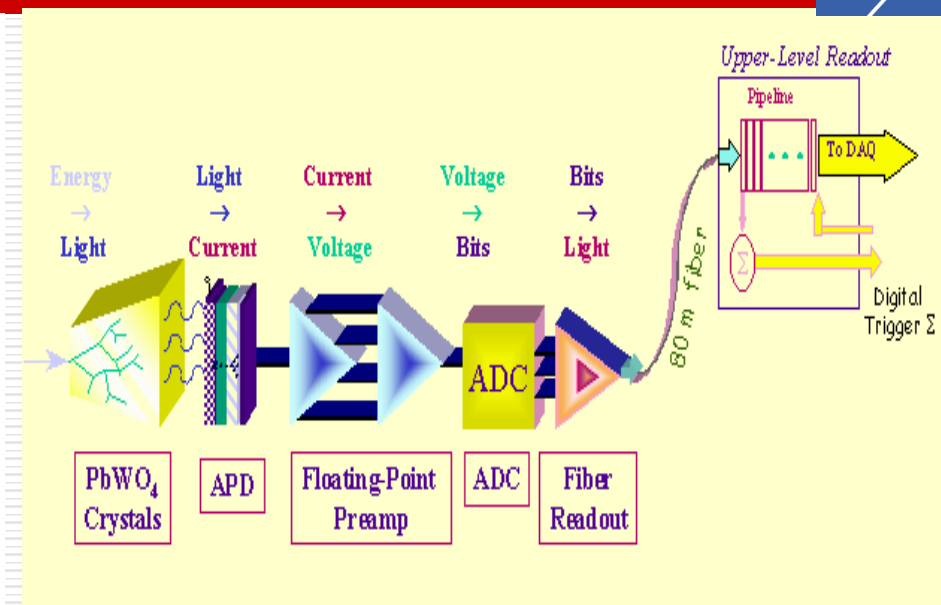
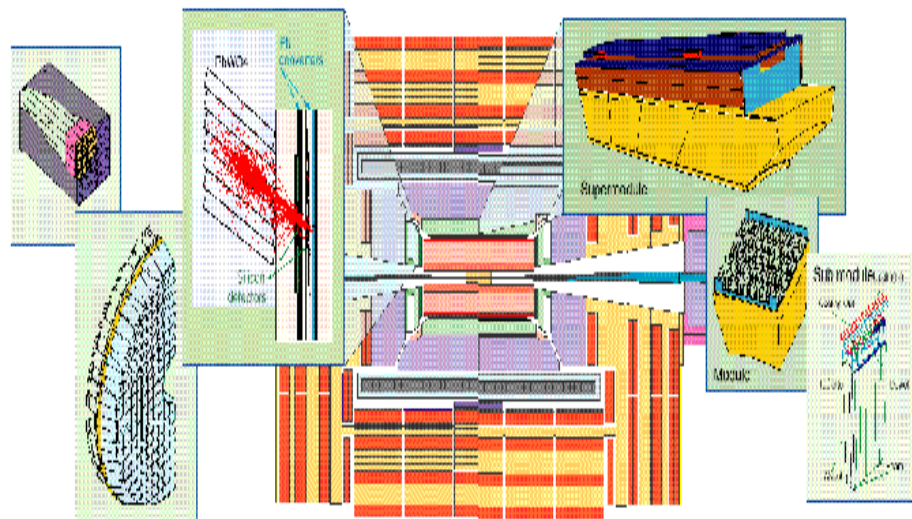
Contributions of UCY-HEP

1. Member of the Consortium for constructing 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 (Convenership)**
7. **Monte Carlo Simulation** → LHC Computing GRID Tier2
8. **Analysis** → Early Resonances, Heavy Flavor Physics, Bose Einstein Correlations, searches for the SM Higgs, and for MSSM, NMSSM higgs bosons, data quality for ECAL & Tracking
9. Organizing **CMS Meetings & CERN Schools in Cyprus:**
CMS Week (2008), CSC 2013, COST Action FAST 2018

First wheel: CMS Barrel Yoke



Disks (small angles)



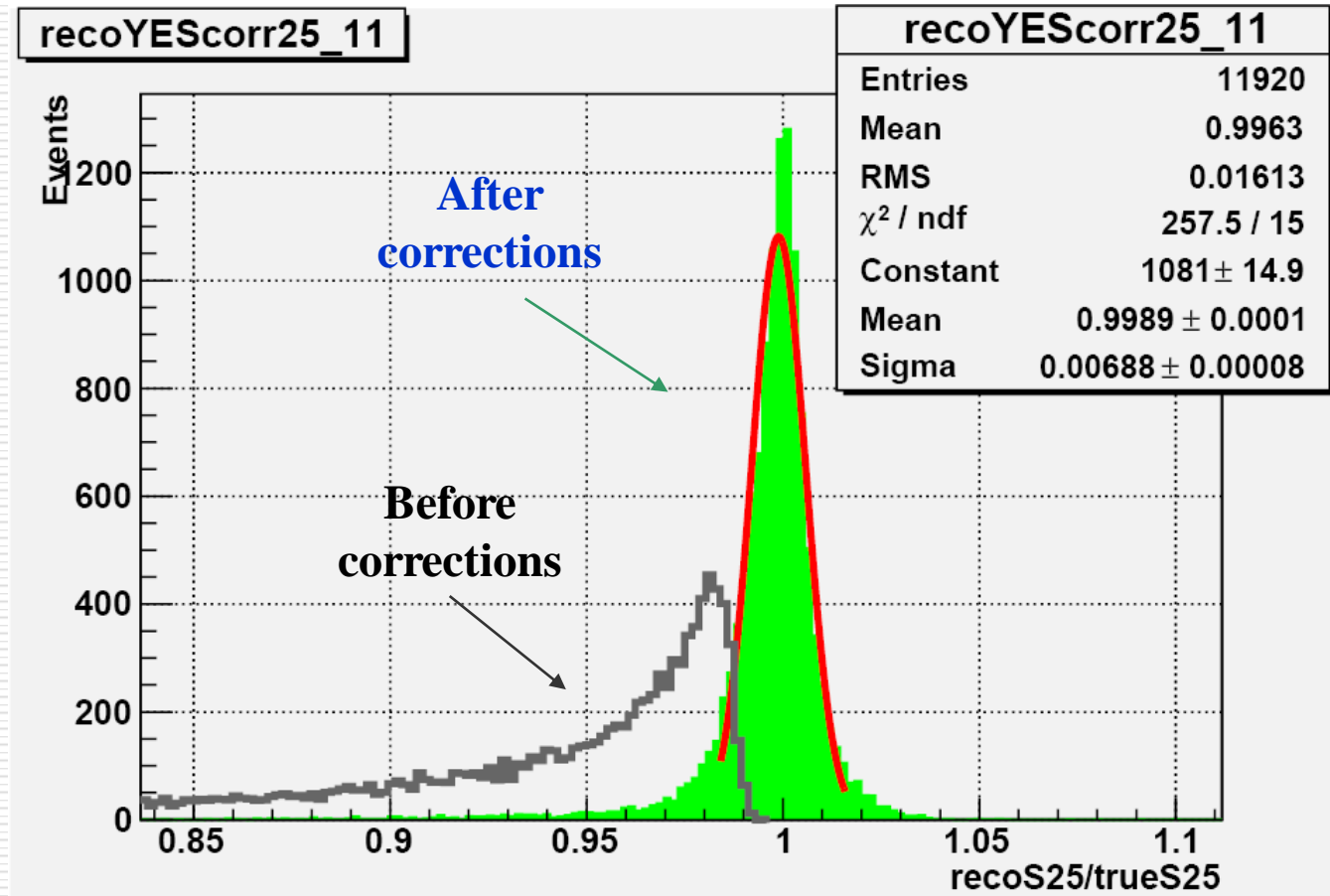
Participation in the construction of **ECAL** Detector
 Calibration and Study of the **VFE** Cards:

- (a) Response vs Radiation
- (b) Temperature and HV changes
- (c) Electronic Noise
- (d) Energy distribution
- (e) Signal Amplification
- (f) Quantum Efficiency
- (g) Collection Time
- (h) Light Production

Collaboration with: CERN, Lyon, ETH

Electromagnetic Calorimeter

ECAL Energy Correction in CMS



Calibration of ECAL Energy Deposition
Correcting the energy of “dead crystals”



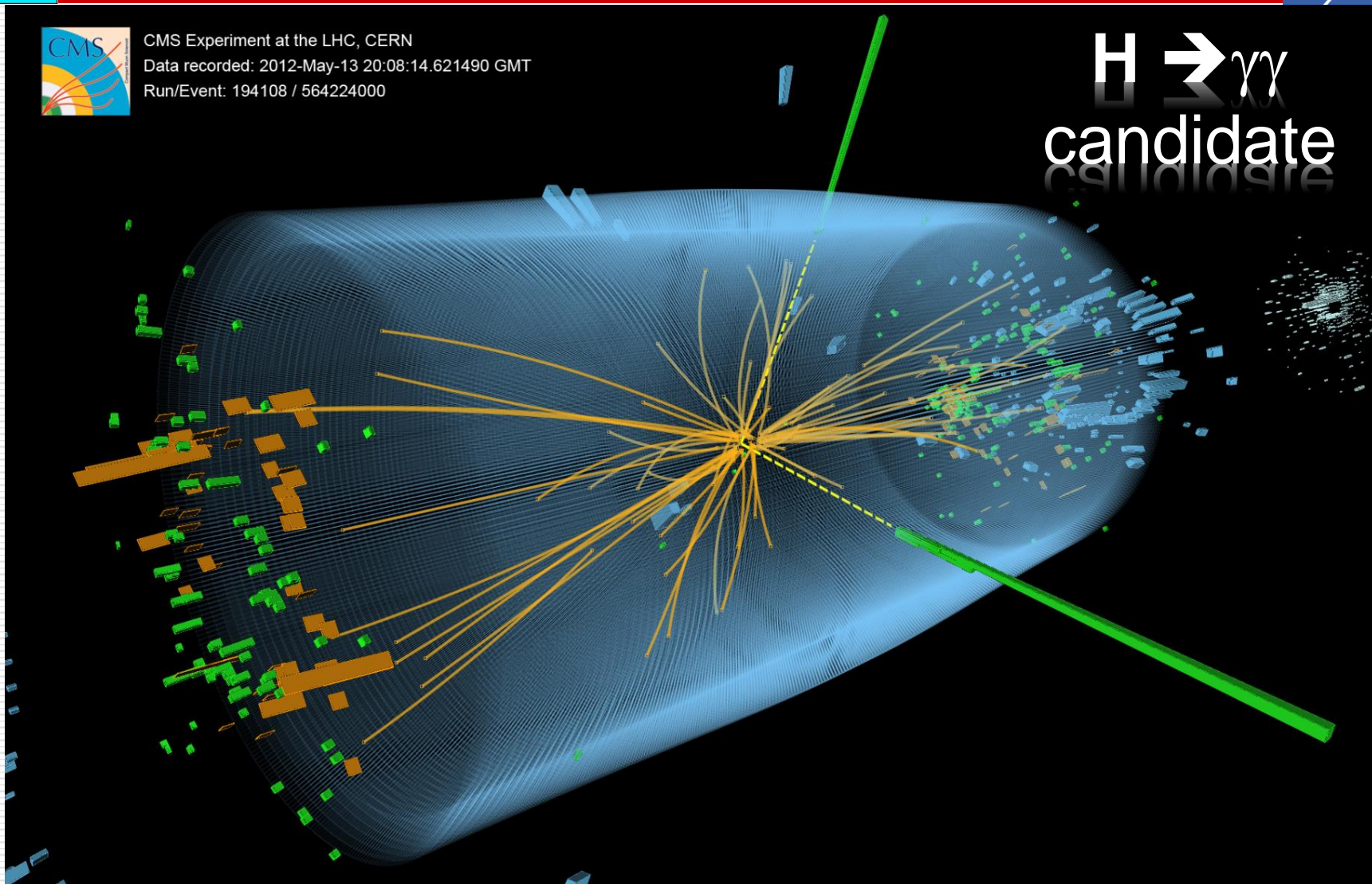
CMS Week-Cyprus (2008) **CSC2013 UCY-Campus**

Search for the Higgs ($H \rightarrow \gamma\gamma$)



CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000

$H \rightarrow \gamma\gamma$
candidate



Candidate for $H \rightarrow \gamma\gamma$

Mass Resolution
 $\Delta m_H / m_H < 1\%$

Irreducible background:

$q\bar{q} \rightarrow \gamma\gamma$

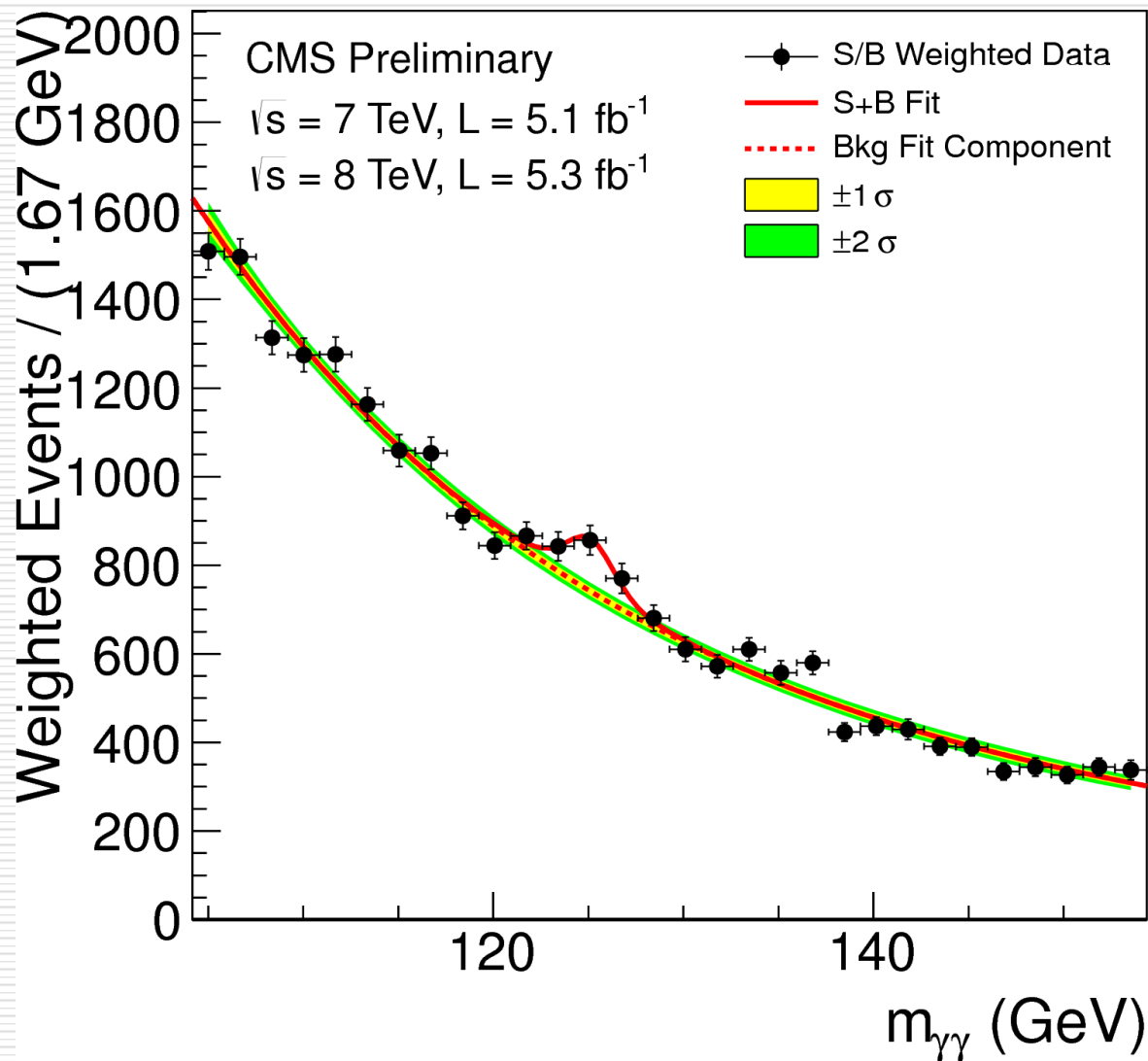
$g\bar{g} \rightarrow \gamma\gamma$

isolated pair production

Mainly reducible background:

$g + \text{jet}$ where "jet" = $\pi_0 \rightarrow \gamma\gamma$

Less than 15% of the irreducible background



Search for the Higgs (CMS, ATLAS)



Nobel Prize 2013
(F. Englert, P. 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”

- All the decay channels of the Higgs
- Energy CM, 7 & 8 TeV
- Standard Model for the Higgs $> 5\sigma$

Discovery after 50 years!

Latest UCY-HEP **Physics Analysis** contributions:

- **Search** for $H^\pm \rightarrow \tau^\pm \nu(\tau \rightarrow h)$ where $m_{H^\pm} \leq 160 \text{ GeV}/c^2$
- **Search** for light CP-even NMSSM higgs: $h^0 \rightarrow a^0 a^0 \rightarrow 4\tau, 4b, 2\tau 2b$
- **Measurement** of the $ZZ \rightarrow 4\mu$ 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** $H \rightarrow \gamma\gamma$ (simulation and ECAL resolution improvement algorithms)
- **Search for additional Higgses under the 2HDM+S model**
 $h(125) \rightarrow aa \rightarrow 2b2\tau$ **and** $h(125) \rightarrow aa \rightarrow 2\mu 2\tau$
 $H^\pm \rightarrow tb$ **with fully hadronic final state**
 $A \rightarrow Zh \rightarrow l^+ l^- (\nu\bar{\nu}) b\bar{b}$

**Analysis presented under
separate talks**

Activation of Cyprus Industry



Sextupole Magnets

CNE Technology, Nicosia

UCY-HEP: KM3NeT (ESFRI)



1st Generation:

$E_{\mu} > 1 \text{ GeV}$, $A_{\text{eff.}} \sim 100\text{-}1000 \text{ m}^2$

2nd Generation: $E_{\mu} > 5\text{-}100 \text{ GeV}$

$A_{\text{eff.}} \sim 0.1\text{-}1 \text{ km}^2$

ORCA: ν Oscillation Research

ARCA: Astronomy Research

TDR and Lol ready for a Deep-Sea Research Infrastructure in the Mediterranean Sea incorporating a Very Large Volume Neutrino Telescope

→ Astroparticle Physics currently being coordinated at CERN

Full Partner → now Observer (waiting budget to sign MoU)



Protocols Cyprus-CERN (Physics)

CYPRUS signs collaboration with CERN (5/10/2012)

Participation of Universities and Scientific Institutions from Cyprus in the High-Energy Particle Physics Programme at CERN

- 12.1 Scientific and technical personnel participating in the CMS Experiment**
- 12.2 Travel expenses and subsistence payments for participating in the CMS Experiment**
- 12.3 Participation in the Construction, Maintenance and Operation of the CMS Experiment**
- 12.4 Expenditures for Materials, Services and Equipment at CERN**
- 12.5 Expenditures for Materials and Equipment in the Republic of Cyprus**
- 12.6 Theoretical Physics funds**
- 12.7 Other Physics Projects at CERN linked to High Energy Physics**
- 12.8 Workshops – Schools**



Protocol Cyprus-CERN (Computing)

Participation of Universities and Scientific Institutions from Cyprus in the High-Performance Computing and Applications Programme at CERN

12.1 Enabling Grids for E-science

12.2 LHC Computing Grid Project (LCG)

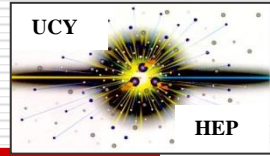
12.3 CERN Openlab for DataGrid Applications

12.4 Other projects at CERN linked to High-Performance Computing

Technical Protocols must be extended and receive more support by the Republic in terms of budget needed and manpower



UCY-HEP: Future Plans



1. Upgrade of CMS for the HL-LHC program at CERN

- **Hadron calorimeter upgrade:** Develop testing station for the Hadron Granularity Calorimeter electronics
- **Trigger upgrade:** collaborate with Greek Universities (Ioannina, Athens) on trigger algorithms and simulation

2. Education Program, Virtual Visits at CERN, Distance Learning

3. Medical Physics at CERN

- **Network HERMES (CERN, Greece, Cyprus):** universities, medical centers, companies, research teams, IKY (**see talk E. Dimovasili**)
- **Expand collaboration** with P. Lecoq et al. on the development of detection systems with better resolution/higher granularity and on testing crystals and SiPMs
- **KT- Forum at CERN on Medical Applications**
- **Collaboration with Bank of Cyprus Oncology Center**

4. Business Plan for a Cyclotron Center with PET-CT (ready)

Aim: Network on facilities & instrumentation for diagnosis and therapy using radioisotopes and hadron irradiation (protons, carbon).

There is an expressed interest from investors

Sources of funding and main problems

Funding

1. European Union
2. Cyprus Foundation of Research and Innovation
3. Internal Funds of the Universities
4. Governmental and Semi-governmental Organizations
5. Leventis Foundation
6. Private Organizations and Sponsors
7. Other sources

Main 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, companies, private sector
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 bureaucracy

Elements to follow-up

- 1. Strong program and opportunities to attract researchers**
- 2. Some of our talented students pursue careers abroad**
Z. Zinonos (MPI Munich), A. Petrides (Univ. of Adelaide) A. Alekou (CERN), N. Iracleous (CERN), Ch. Chadjivasiliou (Syracuse)
- 3. Need to establish Research Fellowships for PhD students and more research positions in Cyprus and CERN**
- 4. Extend Technical Protocols of Cooperation with CERN**
Physics, Computing...plus Engineering, Medical Physics, 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 etc...**

Conclusions

- (a) **Strong collaboration with CERN** for many years
- (b) **Two Technical Protocols** signed between Cyprus & CERN
- (c) The UCY-HEP Group established strong involvement in **international and local research projects**
- (d) Strong expertise in the analysis of the **Standard Model & on the Searches** for new particles and phenomena
- (e) Potential of improvement on **several application areas: detectors, electronics, monitoring & control systems, grid computing, medical physics**
- (f) Many activities will further benefit by **increasing the funding & manpower** of the UCY-HEP Group
- (g) Colleagues working in **several other fields** are invited to join

BACKUP MATERIAL

□ **Detector:**

- **ECAL:** data quality monitoring
- **Tracker:** channel status monitoring, tracker calibration

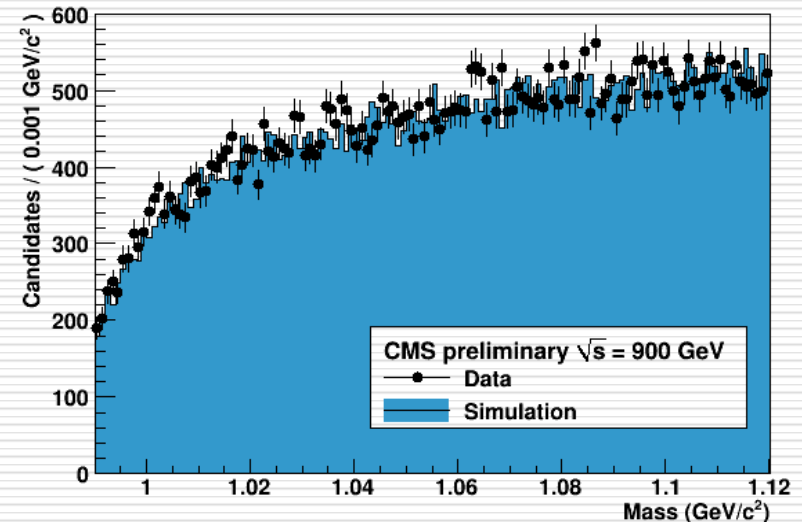
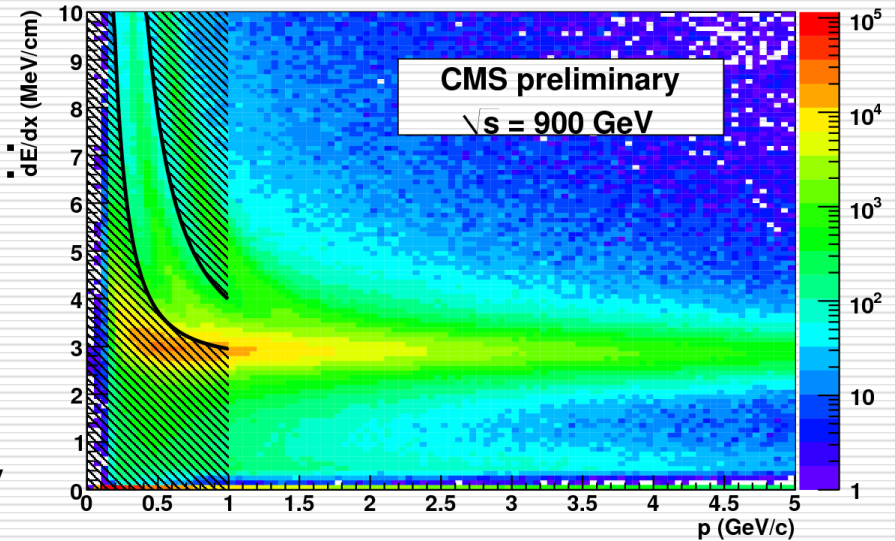
□ **Physics analysis:**

Participation in the first CMS/LHC results, data at 0.9 & 2.36 TeV

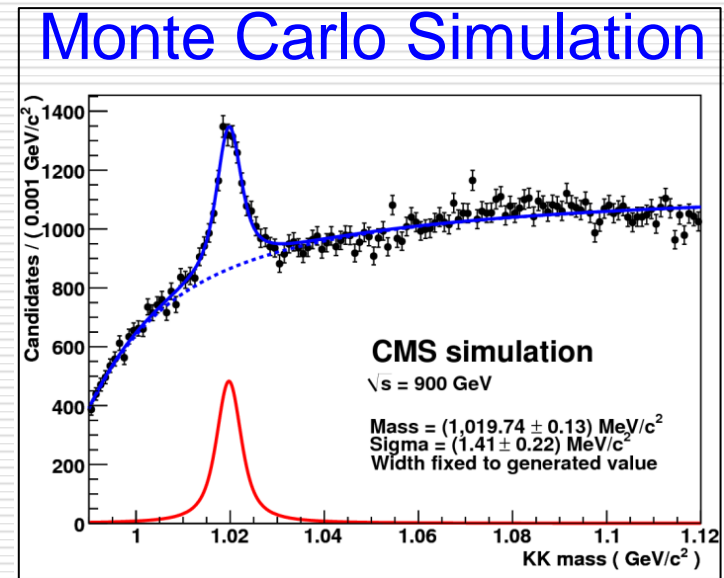
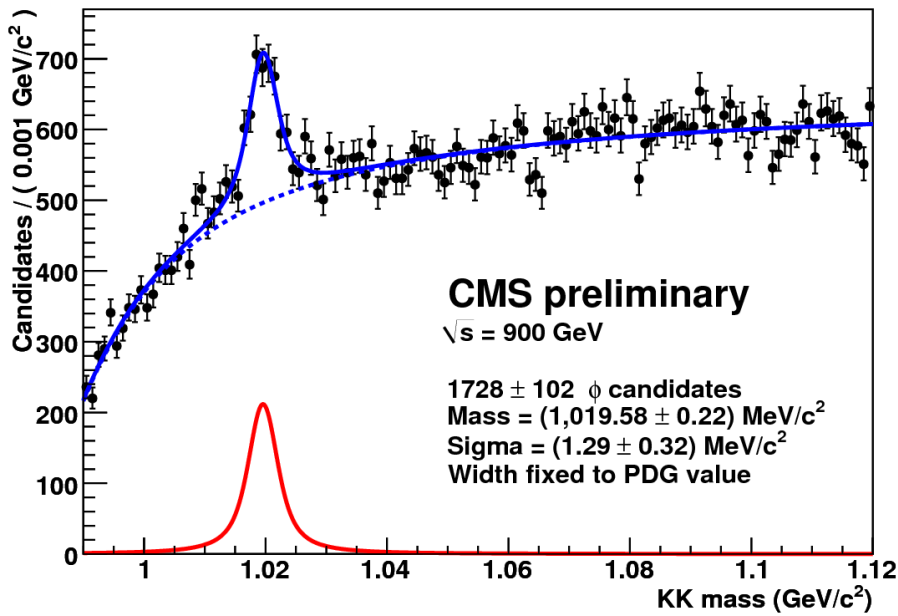
- $\phi \rightarrow K^+ K^-$: tracking performance, dE/dx PID, MC tuning
- **Bose-Einstein correlations** with low p_T min. bi
one of the first few CMS public analysis results
- **b-physics:**
 - $B^0 \bar{B}^0$ mixing using di-muons (tracking, reconstruction, efficiency, fakes, MC tuning and generation)
 - $b\bar{b}$ correlated production cross section

Target: prove/disprove the excess of multi-muon events reported by CDF using 7 TeV LHC data

- ▶ The $\Phi(1020)$ meson is reconstructed looking at its decay into two charged kaons: $\Phi \rightarrow K^+K^-$
- ▶ K^\pm are reconstructed in the CMS tracker
- ▶ Event and track selection
 - ▶ “Minimum bias” events at $\sqrt{s}=0.9$ TeV
 - ▶ Standard track quality cuts
 - ▶ Formed pairs with opposite-curvature tracks identified as kaons
 - ▶ K compatibility requested only for tracks with $p < 1$ GeV
- ▶ If at least one track fails the dE/dx cut, no peak is visible

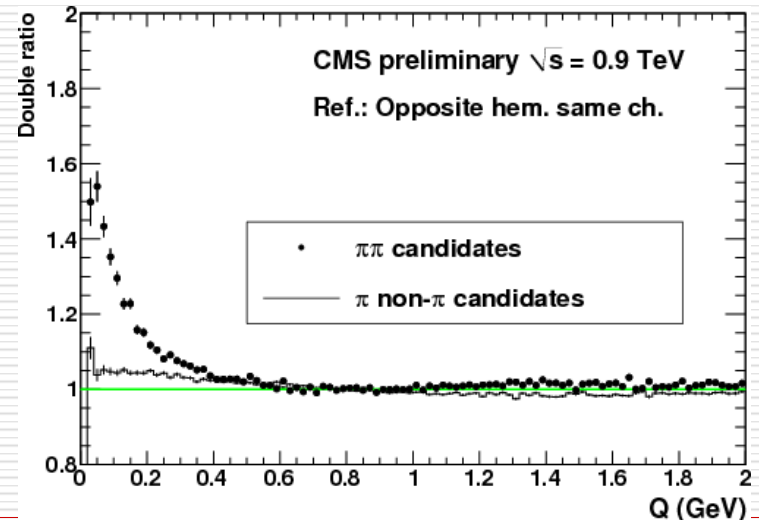
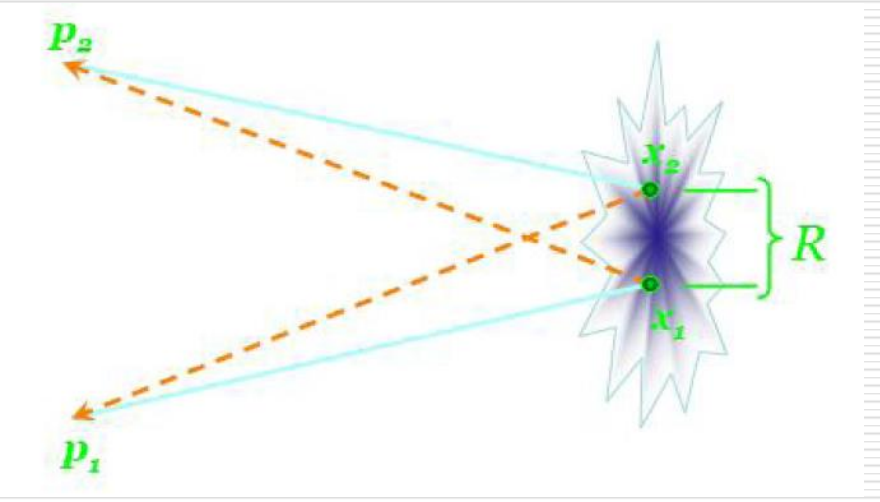


- ▶ Mass and resolution is in very good agreement respectively with PDG and simulation
- ▶ Differences in S/B depend from bad MC reproduction of data – under investigation by CMS
- ▶ Result in a public CMS note (CMS PAS TRK-10-001), a paper is in preparation

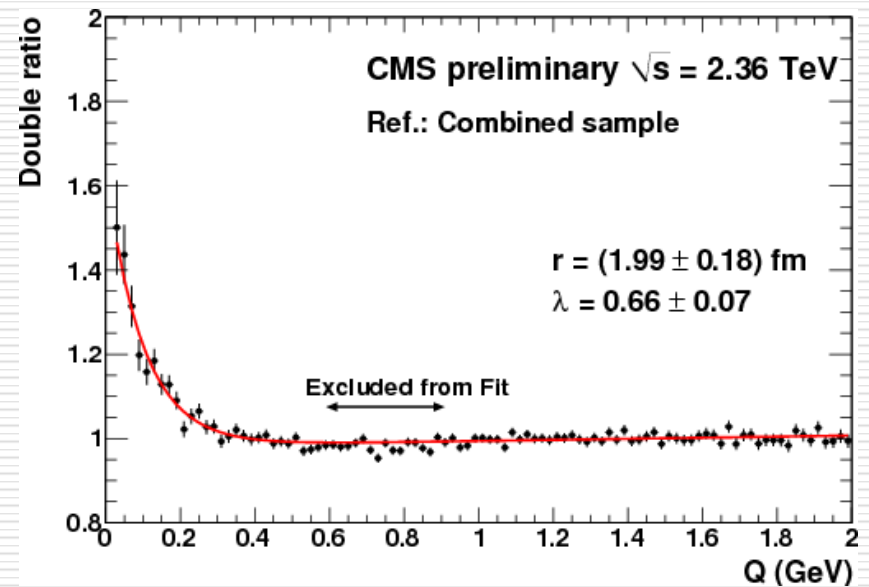
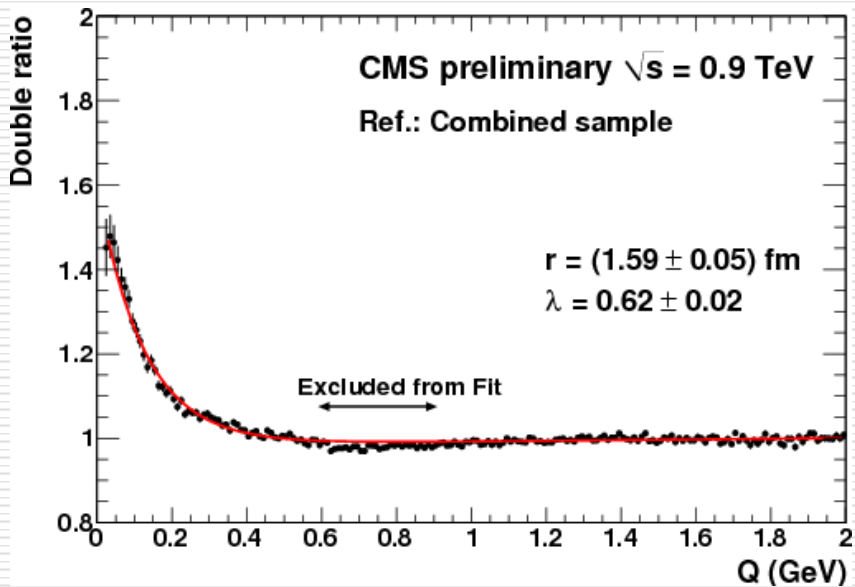


- ▶ Probability for identical boson particles (**signal**) to have similar momenta is enhanced with respect to uncorrelated case (**reference**) due to Bose-Einstein statistics
- ▶ Studied as a ratio $R(Q)$ between the signal and a reference distribution
- ▶ Q depends on the 4-momentum difference between the two particles

$$Q = \sqrt{p_1 p_2 - 4m_s^2}$$
- ▶ Distorsions due to reference are treated using double ratios $R_{\text{data}}/R_{\text{MC}}$ and looking at several reference samples (7 in our case)
- ▶ We verified that BEC is only present for identical particles



- ▶ BEC is seen as an enhancement of the ratio at low Q-values
- ▶ The ratio is fitted assuming an exponential form of the correlation
 - ▶ Gaussian form (more used in literature) is very disfavored by our data
 - ▶ Some regions are excluded from the fit due to bad modeling of resonances in MC
 - ▶ The fit gives information on the size and shape of the particle-emitting region and on the strength of the correlation
- ▶ These are the first measurements of the BEC in proton-proton collisions at 0.9 TeV and the first absolute measurement of BEC at 2.36 TeV



- ▶ We found an interesting effect linking the parameters of BEC to the total charged multiplicity in the event
- ▶ The radius r is found to increase significantly with N_{tracks}
- ▶ This effect is present in 0.9 TeV and in 2.36 TeV data (not shown in figure)
- ▶ This has already been measured by other experiments in the past, although it seems that there is no simple theoretical explanation for it
- ▶ Results in a public CMS note (CMS PAS QCD-10-003) and a paper

