CMS @ LHC

CMSday at IST

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N. Leonardo

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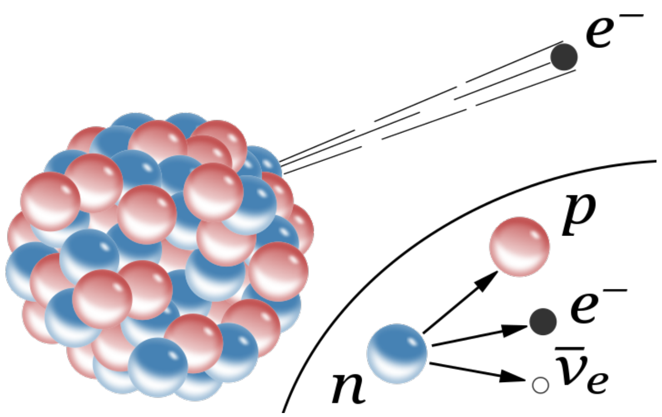
Zoom, 09.10.2020

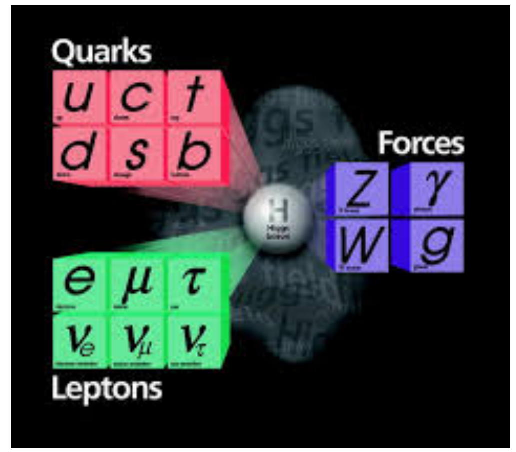
LIP

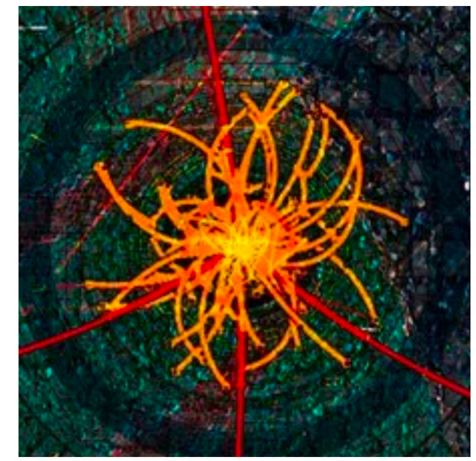
TÉCNICO LISBOA

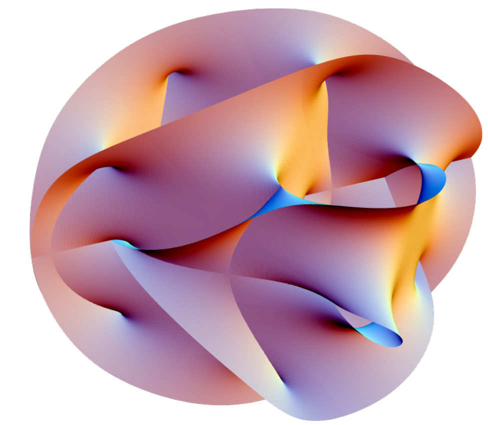
energy scale — $m_{Z,W}$ m_H m_t Λ_{NP}

1930 … 1970 2012 2020 … future

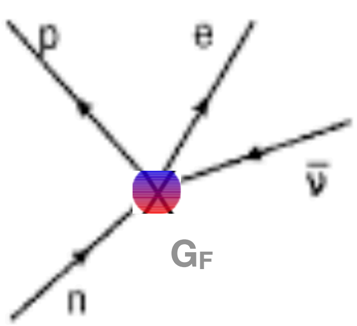


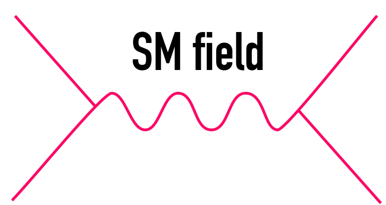


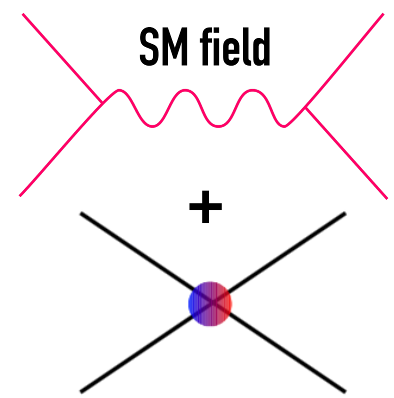


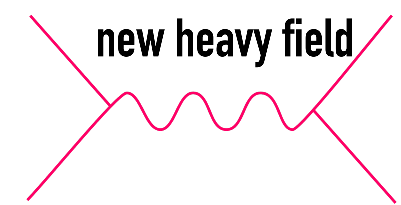


Fermi model	Standard Model	SM-EFT	UV theory









$$\mathcal{L}_{\text{Fermi}} = -\frac{G_F}{\sqrt{2}}\,\bar{p}\gamma_\mu n\,\bar{e}\gamma^\mu\nu + \text{h.c.}$$

$$\mathcal{L}_{\text{SM}} = \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{higgs}}$$

$$\mathcal{L}_{\text{SM-EFT}} = \mathcal{L}_{\text{SM}} + \Sigma_i C_i O_i$$

a predecessor of EWK theory

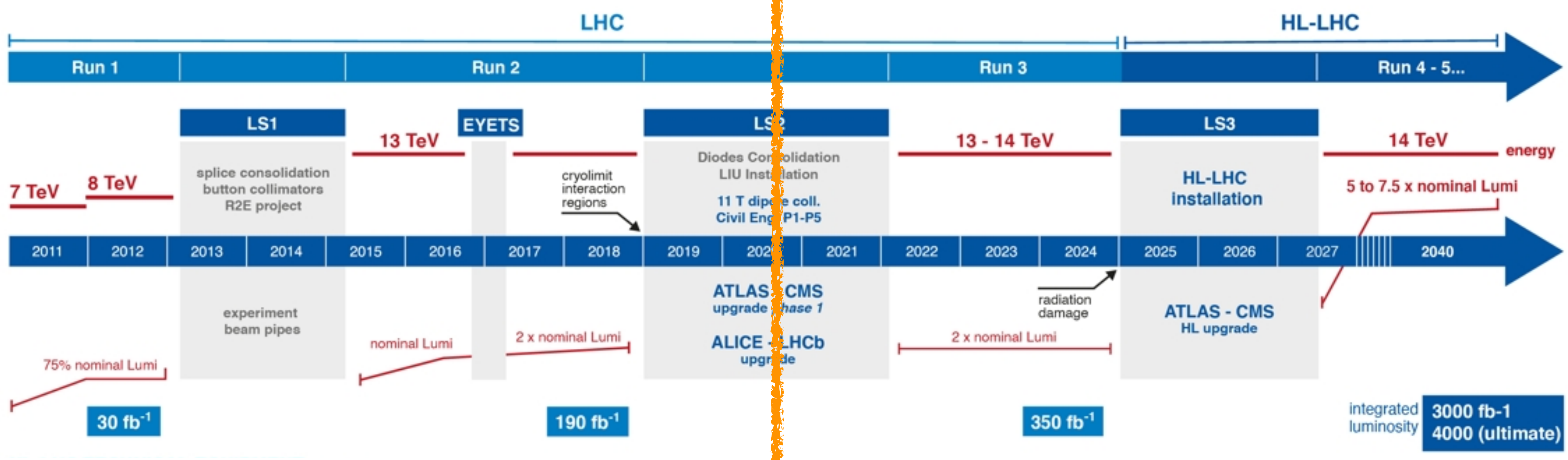
simple and elegant theory describing *almost* all microscopic phenomena

we're here!

a more fundamental theory with new degrees of freedom

strategy!

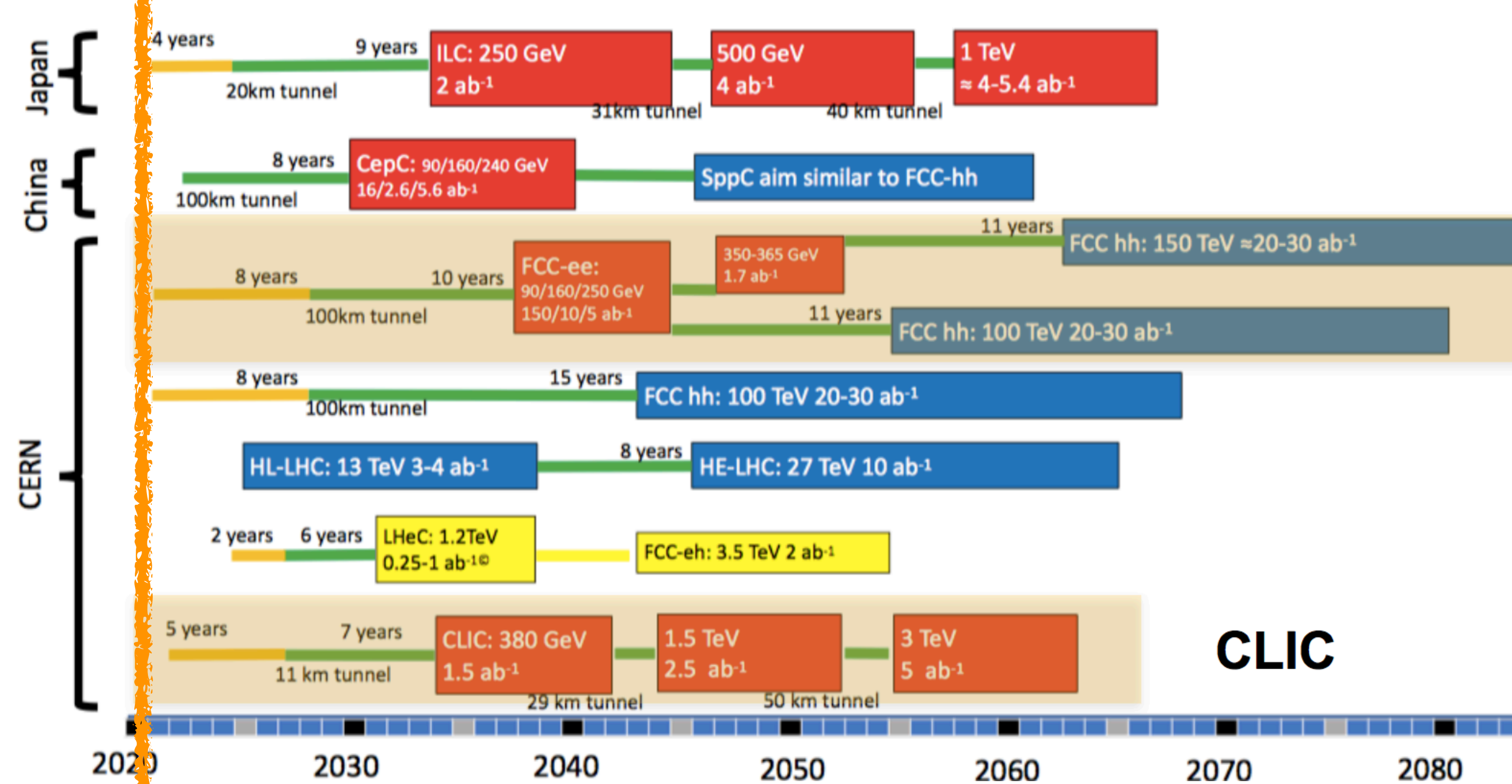
European Strategy Update

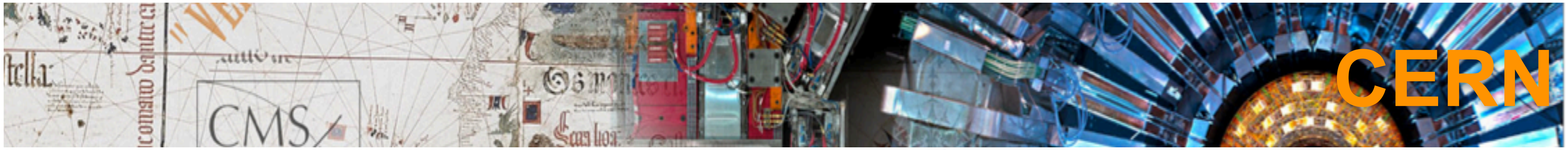


Menu / Priority

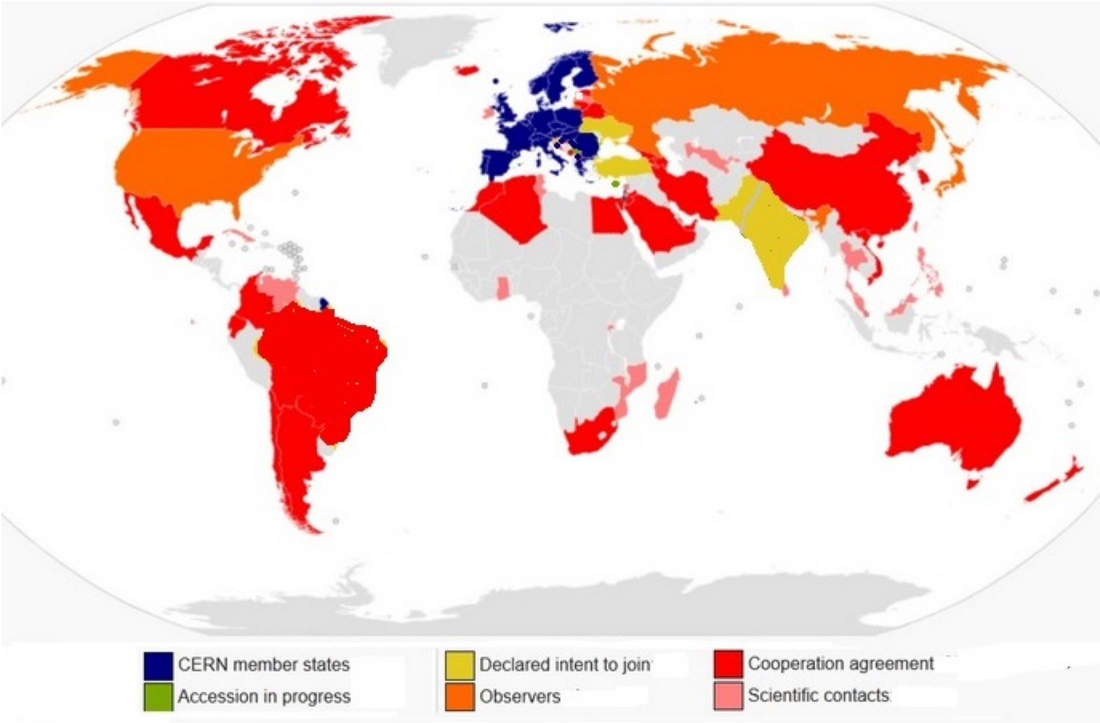
- Hoje:
  - **LHC**
- Amanhã:
  - **HL-LHC**: a new LHC!
- Depois de amanhã:
  - **FCC-ee**: precision!
  - **FCC-hh**: a super-LHC!

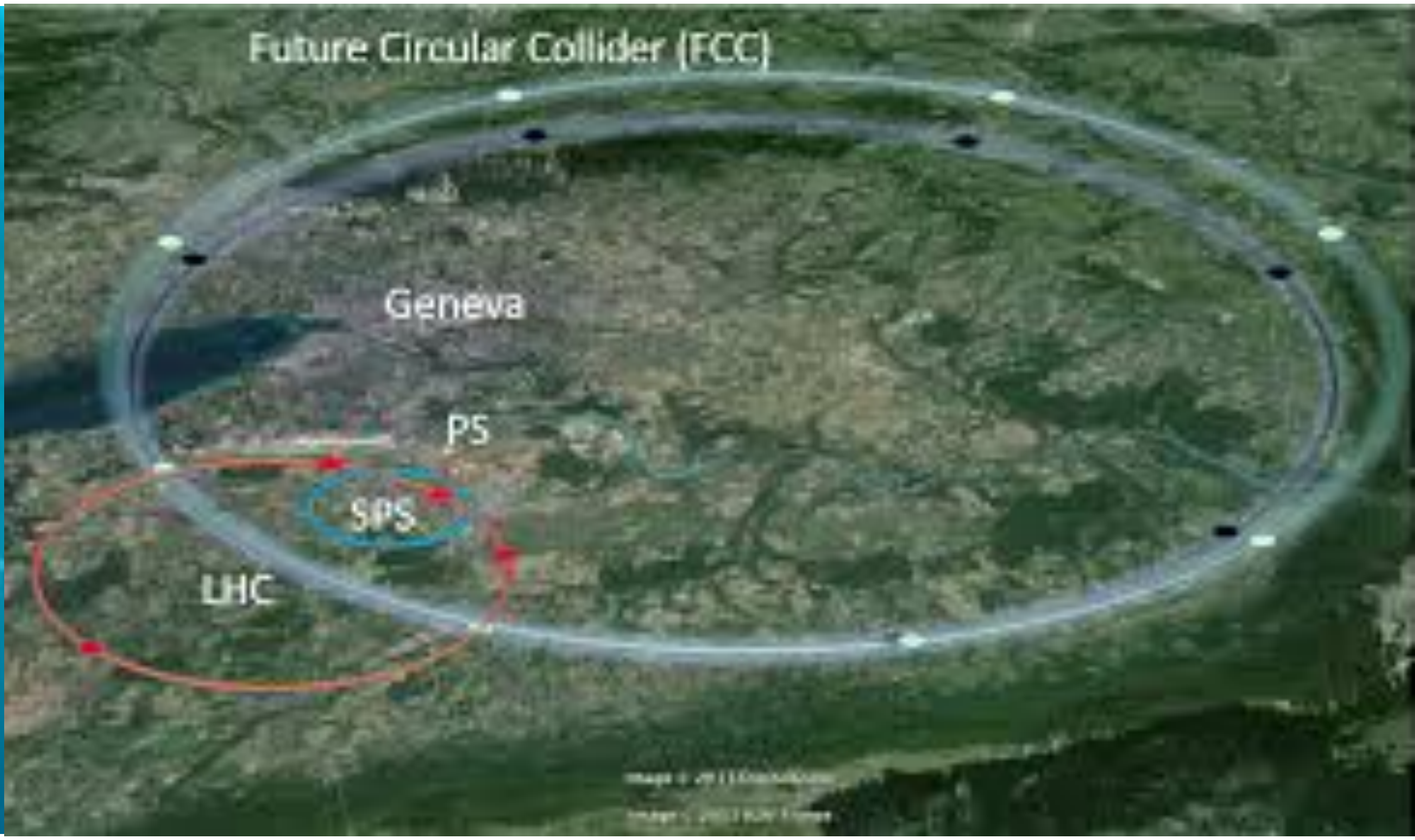
[meeting last week @ IST]

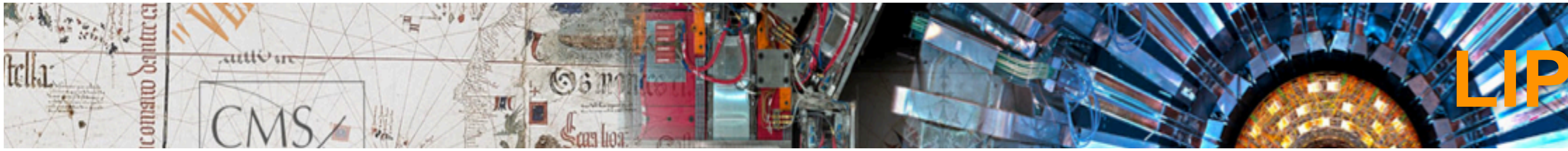




- Europe at center stage of particle physics
- CERN model of **world-wide** scientific cooperation







- LIP: **Particles & Technology**
  - Physics
  - Instrumentation & Computing
  - Advanced Training
- National partner lab of CERN
- FCT evaluation **Excellent**

report

boletim

LIP INTERNSHIP PROGRAM

COIMBRA LISBOA MINHO

internship program

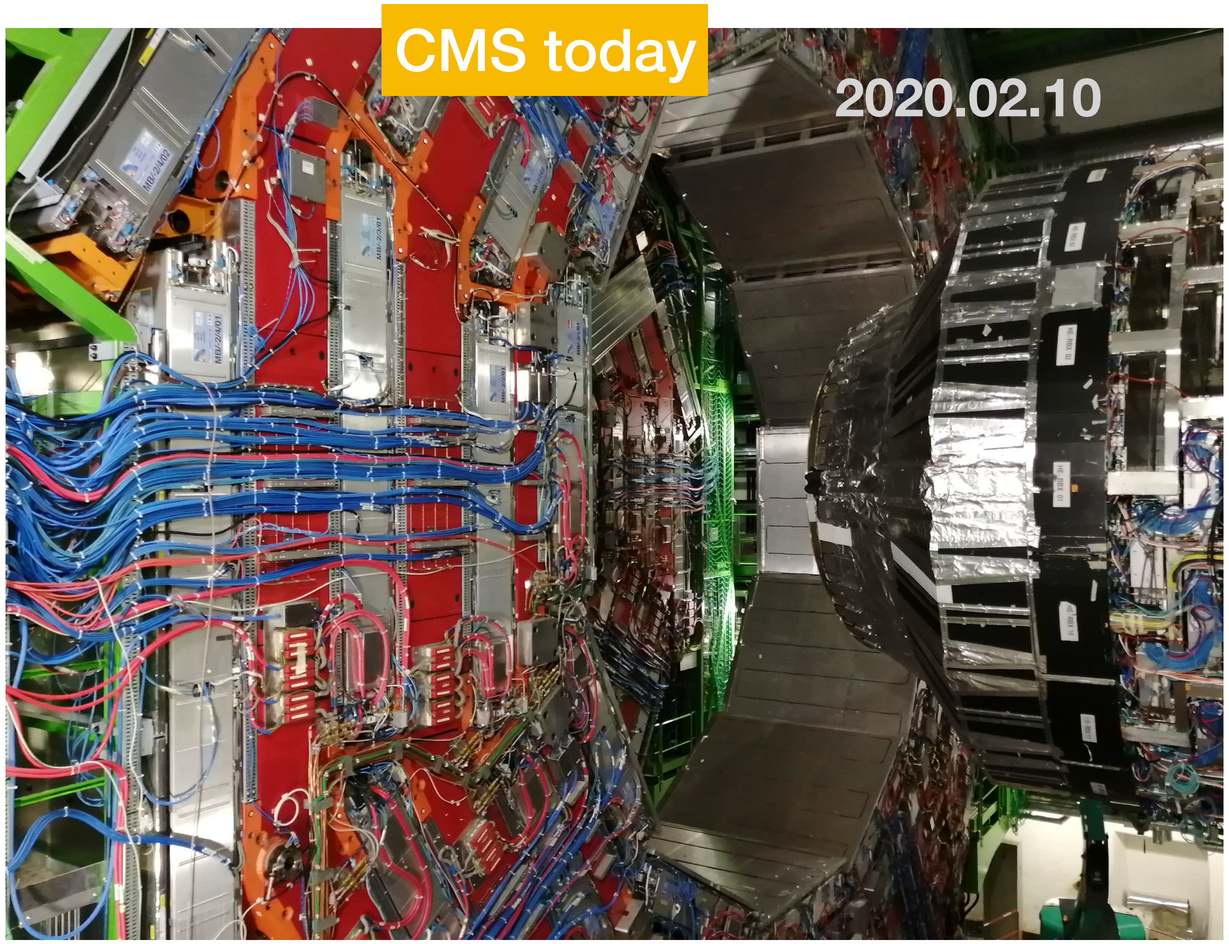
"The LIP-CMS group, while small in size, is really outstanding and world-class.

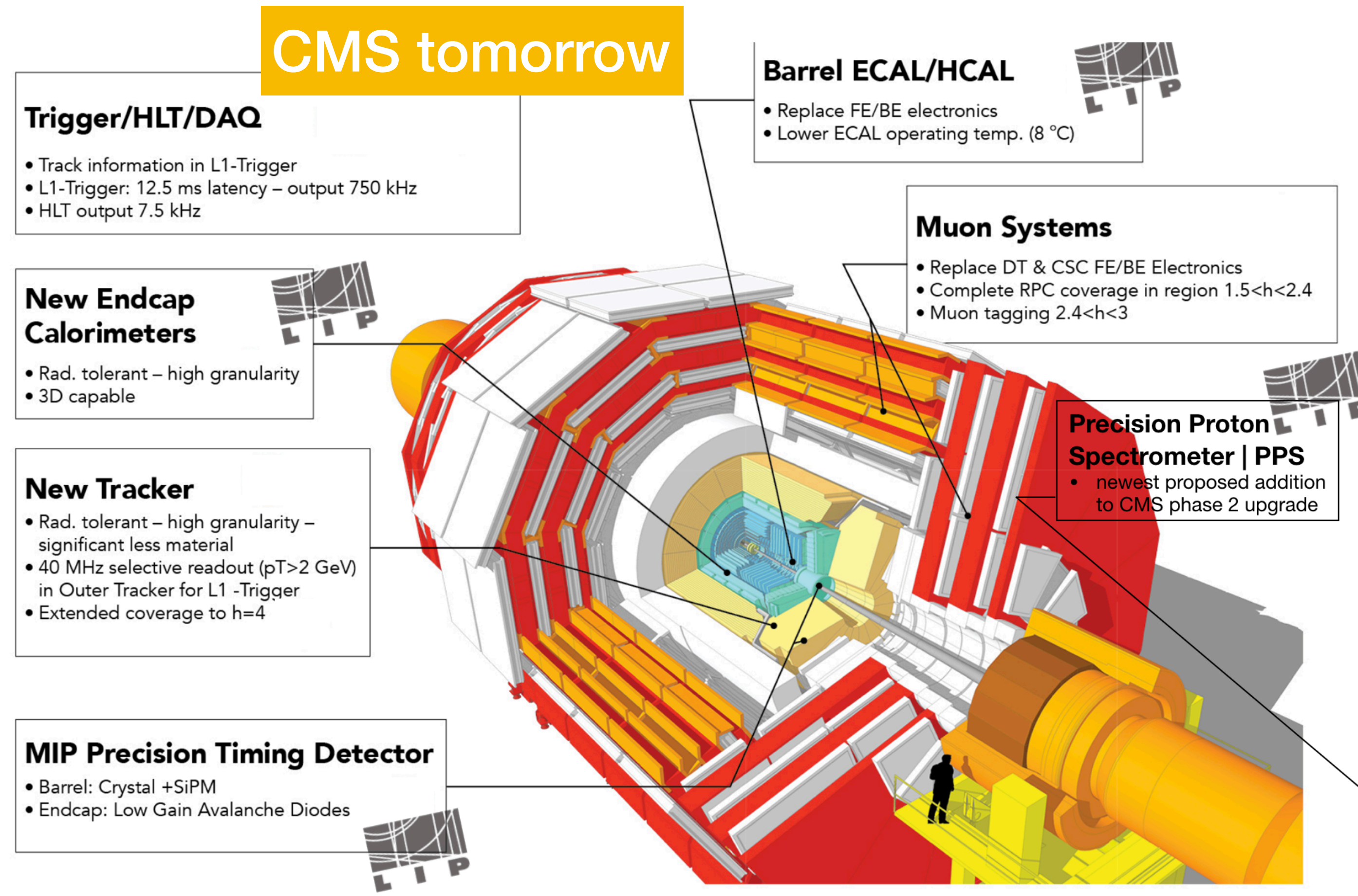
A member of LIP was deputy **spokesperson** of the CMS collaboration at the time of the **Higgs discovery**, and has supplied physics working group co-conveners of the CMS **Higgs** Physics analysis, the **Top** Quark Physics analysis and the CMS **B** and **Quarkonium** Physics group. This is a **remarkable** achievement for such a small group, to be **leading** three of the most important physics analysis groups."

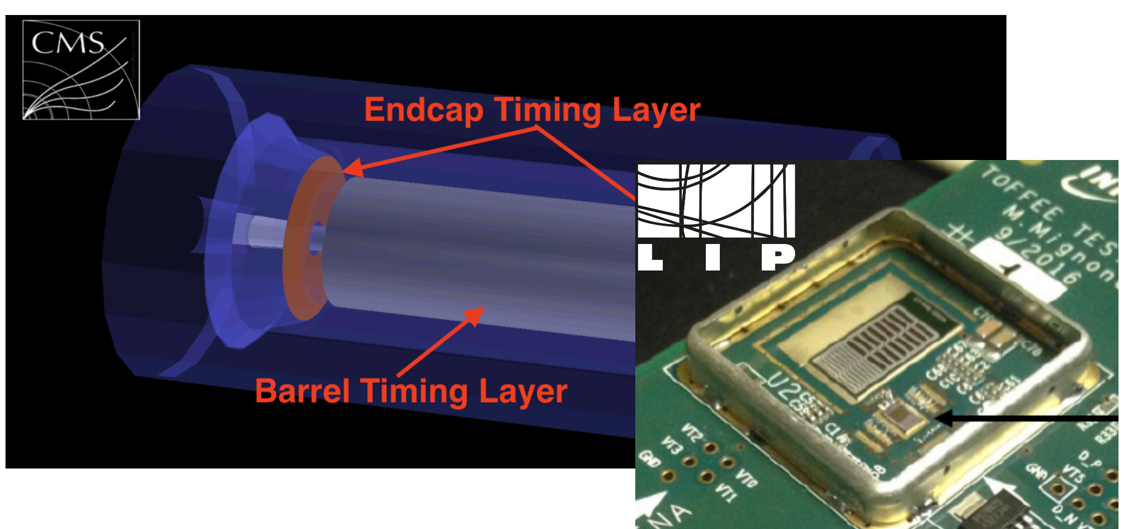
FCT international review panel

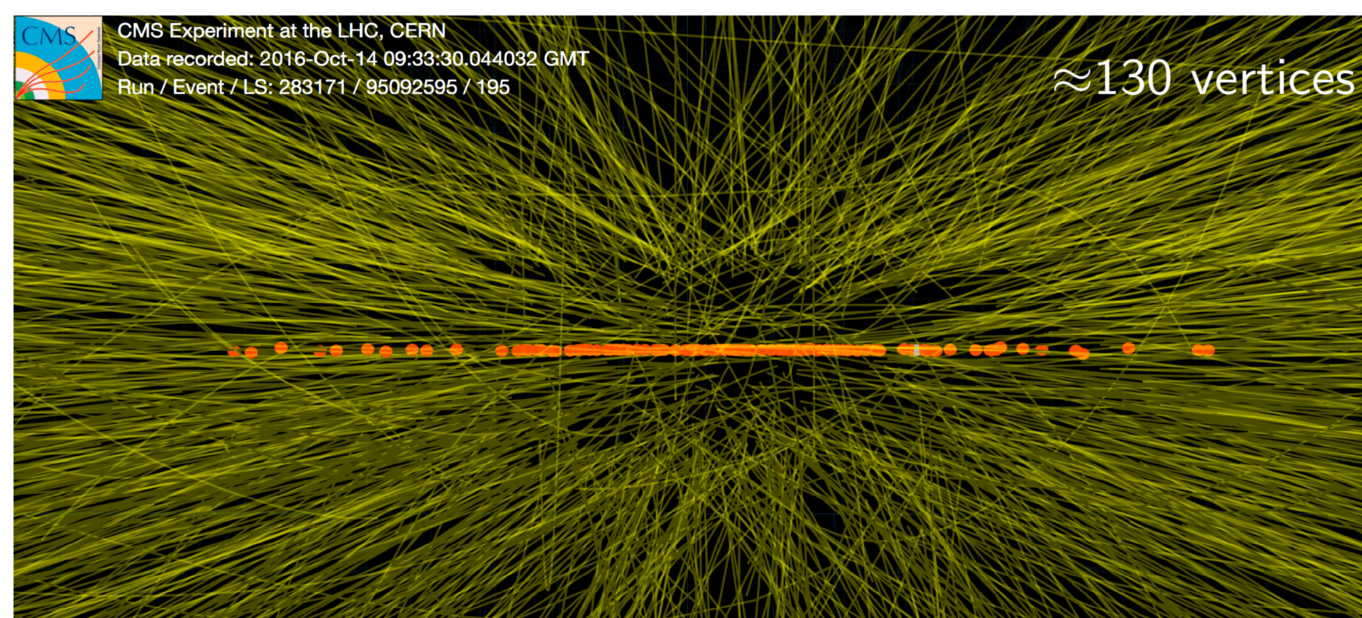
The LIP-CMS group (in pictures)

The CMS detector

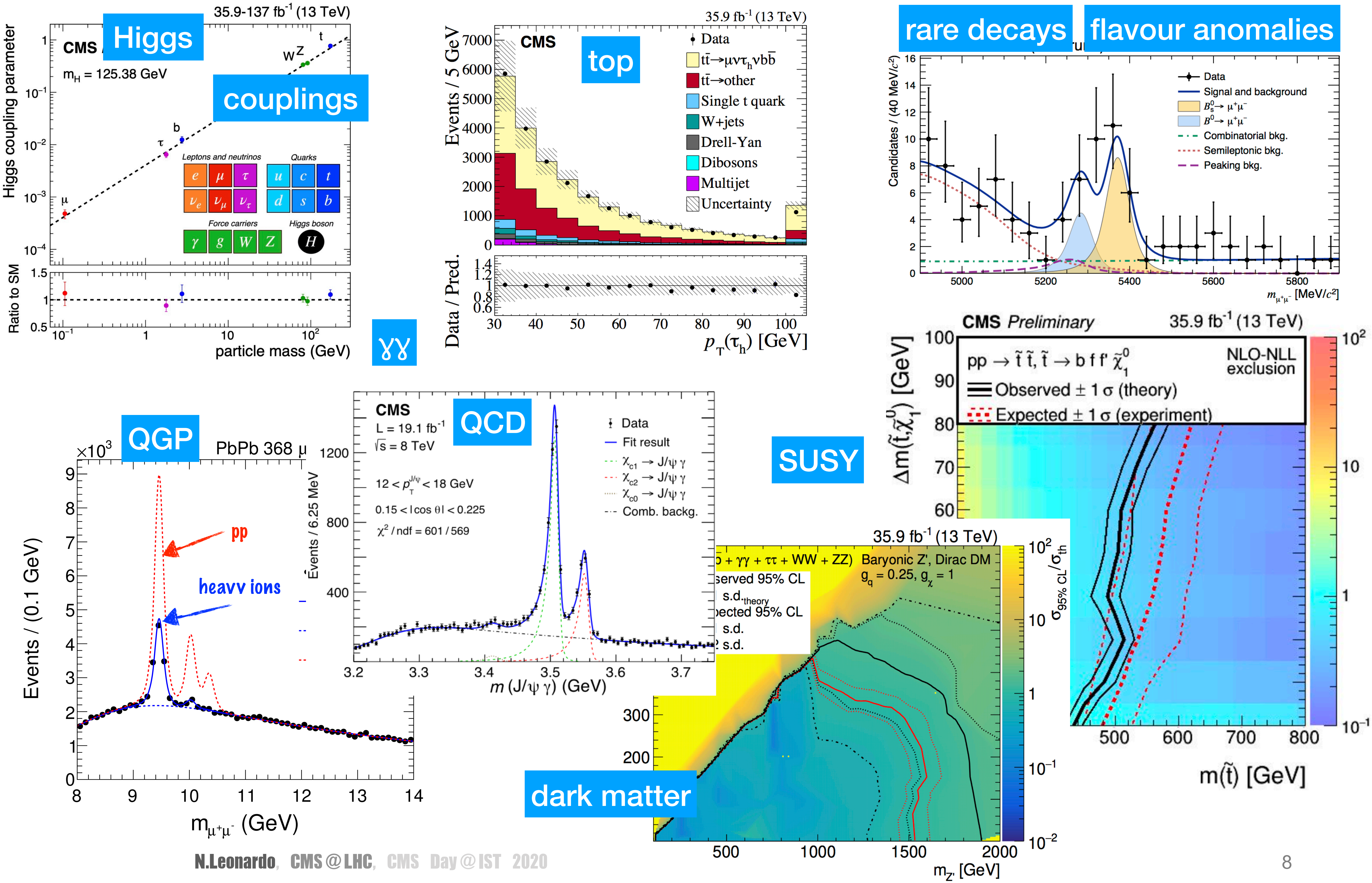




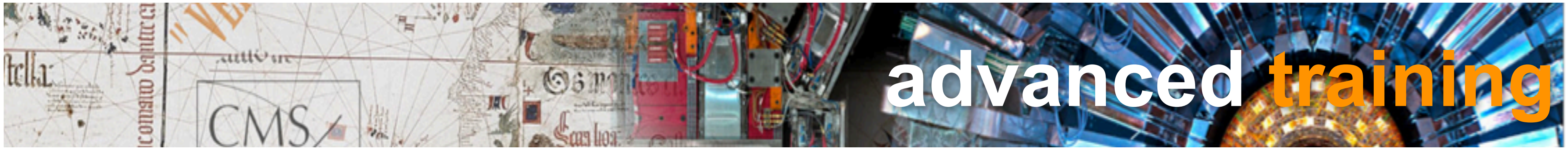




Physics



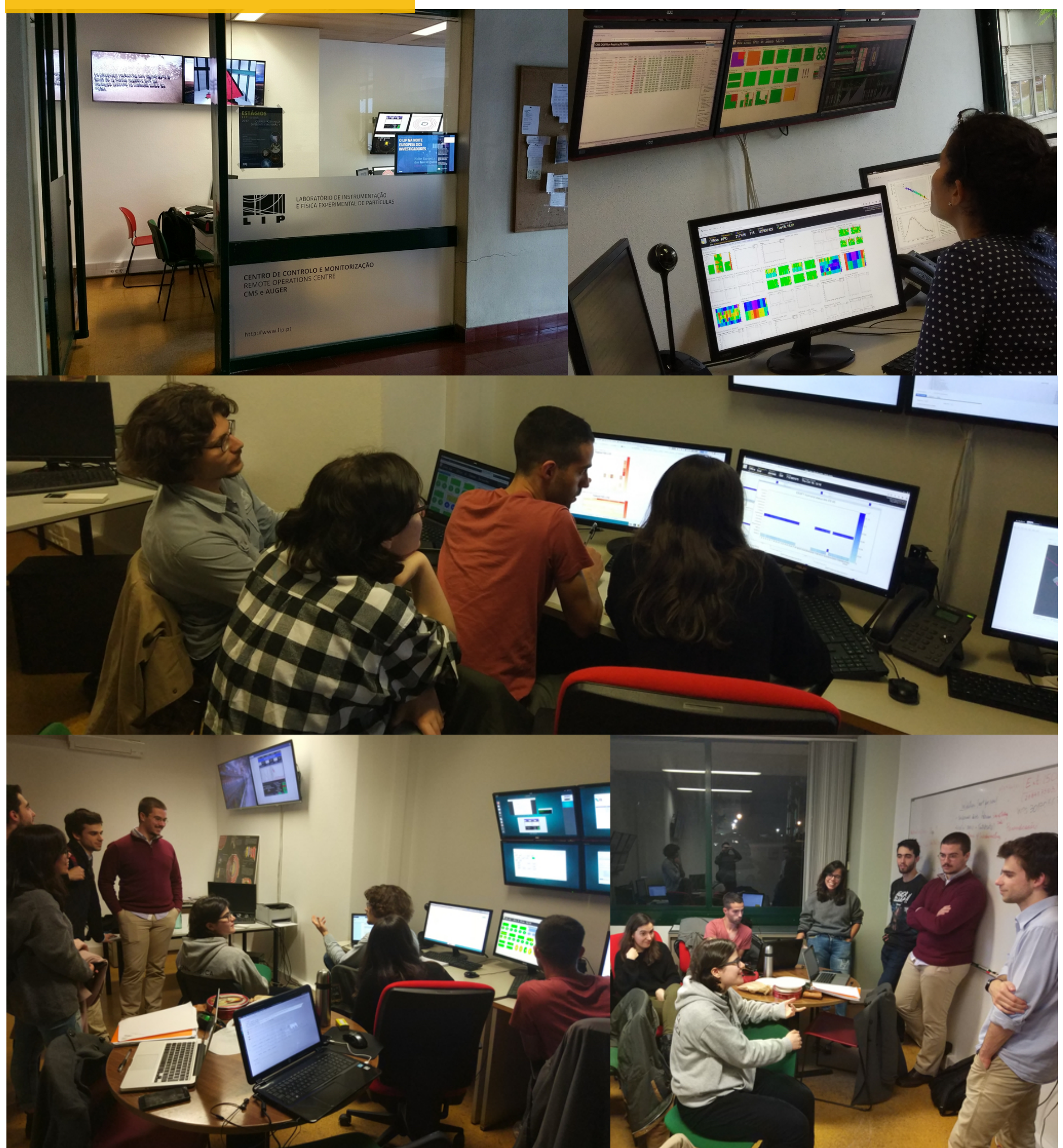
Higgs
couplings
35.9-137 fb⁻¹ (13 TeV)
CMS
m_H = 125.38 GeV
Higgs coupling parameter
Ratio to SM
particle mass (GeV)
Leptons and neutrinos
Quarks
Force carriers
Higgs boson
top
35.9 fb⁻¹ (13 TeV)
Data
Single t quark
W+jets
Drell-Yan
Dibosons
Multijet
Uncertainty
Events / 5 GeV
Data / Pred.
rare decays
flavour anomalies
Data
Signal and background
Combinatorial bkg.
Semileptonic bkg.
Peaking bkg.
Candidates / (40 MeV/c²)
γγ
QGP
PbPb 368 μ
pp
heavy ions
Events / (0.1 GeV)
QCD
CMS
L = 19.1 fb⁻¹
√s = 8 TeV
0.15 < |cos θ| < 0.225
χ² / ndf = 601 / 569
Data
Fit result
Comb. backg.
Events / 6.25 MeV
m (J/ψ γ) (GeV)
SUSY
CMS Preliminary
35.9 fb⁻¹ (13 TeV)
NLO-NLL exclusion
Observed ± 1 σ (theory)
Expected ± 1 σ (experiment)
m(t̃) [GeV]
dark matter
35.9 fb⁻¹ (13 TeV)
Baryonic Z', Dirac DM
g_q = 0.25, g_χ = 1
m_Z' [GeV]



CMS shifts @ IST

internship papers

CMS ROC@IST



LIP-STUDENTS-19-000

Measurement of J/ψ polarization in pp collisions at $\sqrt{s} = 8$ TeV in CMS

Francisco Albergaria[1,a] and Henrique Borges[1,b]

[1] Instituto Superior Técnico, University of Lisbon

Project supervisors: Mariana Araújo, Pietro Faccioli and João Seixas. February 13, 2020

Abstract.
The polarization of prompt J/ψ mesons is measured in proton-proton collisions at $\sqrt{s} = 8$ TeV, using a dimuon data sample collected by the CMS experiment at the LHC. The prompt polarization parameter λ_θ is measured from the dimuon decay angular distributions in the helicity frame. The J/ψ results are obtained in the transverse momentum range $12 < p_T < 70$ GeV and in the rapidity intervals $|y| < 1.5$.
No evidence of large polarization is seen in these kinematic regions, which is in agreement with past results using earlier data. Preliminary results of this analysis are shown here for the first time.

Keywords: Quarkonium, Polarization, NRQCD, QCD, Hadron formation

1 Introduction

Non-relativistic quantum chromodynamics (NRQCD) is the most satisfactory effective theory capable of explaining the production and decay of heavy quarkonium. However, the polarization of J/ψ mesons is not correctly described in this theory, where the purely perturbative colour-singlet production is complemented by processes including possible non-perturbative transitions from colour octet states to the observable bound states. Therefore, it is crucial to analyze the most recent experimental data, which already reaches rather high quarkonium transverse momentum, p_t, (where the calculations are expected to be more reliable [1]), and compare it with the theory predictions. In fact, for high transverse momentum, the directly produced S-wave quarkonia are expected to be transversely polarized with respect to the direction of their own momentum. If inconsistencies between the predictions made by the theory and the experimental results are found, it is important to discover if those discrepancies are originated from approximations and inaccuracies of the fixed-order perturbative calculations available at the moment or from difficulties in the conceptual basis of the theory.

Through the study of the angular distribution of the leptons produced in the $J^{PC} = 1^{--}$ quarkonium states' $\mu^+\mu^-$ decay, we can measure their polarization, determined by the lambda parameters, from the expression provided by Quantum Mechanics:

$$W(\cos\vartheta,\varphi) = \sum_{i=1}^{n} f^{(i)} W^{(i)} = \Big(1 + \lambda_\theta \cos^2\vartheta + \lambda_\varphi \sin^2\vartheta \cos 2\varphi + \lambda_{\varphi\vartheta} \sin 2\vartheta \cos\varphi\Big)\frac{3}{4\pi(3+\lambda_\theta)}, \quad (1)$$

with φ and ϑ being, respectively, the azimuthal and polar angles of the μ^+, with respect to the z axis of the selected polarization frame [2].

It is important to state that the majority of the theoretical studies on J/ψ polarization are limited to λ_θ, even though all the coefficients give independent information [3]. In this paper (as well), we only considered the $\cos(\theta)$ distribution. However, correct quarkonium polarization measurements require information from all the angular distribution parameters, in at least two polarization frames.

The definition of a coordinate system, with respect to which the momentum of one of the two decay products is expressed in spherical coordinates, is needed for the measurement of the distribution under study. In inclusive quarkonium measurements, the reference frame axes are fixed with respect to the physical reference provided by the directions of the two colliding beams as seen from the quarkonium rest frame. In this analysis, we considered the helicity frame, HX, that is the opposite of the direction of motion of the interaction point (i.e. the flight direction of the quarkonium itself in the center-of-mass of the colliding beams), as stated in [4]. A formal and intuitive description of the three most used definitions of the polarization axis z (decay reference frame) with respect to the directions of motion of the colliding beams and of the quarkonium can be found in the last reference cited.

In this analysis, we considered pp collision data obtained by the CMS experiment in 2012 at $\sqrt{s} = 8$ TeV with both J/ψ mesons in transverse momentum range $12 < p_T < 70$ GeV and in the rapidity intervals $|y| < 1.5$ and a Monte Carlo simulation generated assuming unpolarized production (uniform J/ψ decay distribution).

2 CMS detector and Data Processing

The CMS apparatus [5] was designed around a central element: a superconducting solenoid of 6 m internal diameter, providing a 3.8 T field. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass/scintillator hadron calorimeter. Muons are measured in gas-ionization detectors embedded in the steel return yoke outside the solenoid and made using three technologies: drift tubes,

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LIP-STUDENTS-19-000

B mesons as novel probes of QGP

João Gonçalves[1,a] and Alexandra Pardal[2,b]

[1] Instituto Superior Técnico, Lisboa, Portugal
[2] Faculdade de Ciências, Lisboa, Portugal

Project supervisors: N. Leonardo, J. Silva

Abstract. In this work we study B mesons as novel probes of the quark gluon plasma (QGP). We used PbPb data collected by the CMS experiment at the LHC in November 2018. The B^+ and B_s production differential cross-sections in PbPb collisions are measured. The cross sections of the two mesons and their ratios provide unique information about the properties of the QGP and how the hot and dense QCD medium affects the hadronization of the b quark. The B_s meson is observed for the first time in heavy ion collisions.

Keywords: LHC, QGP, B mesons, production cross sections, energy loss, strangeness enhancement

Contents

1 Introduction

Quantum chromodynamics (QCD) predicts that under extreme conditions of temperature and/or density the Quark-Gluon Plasma (QGP) is formed. The QGP existed microseconds after the Big Bang and it is a state of matter formed by deconfined quarks and gluons. It can be recreated at the LHC by colliding heavy nuclei (Pb) at the highest energies. [1]

B mesons are composed by a bottom antiquark ($\bar{b}$) and an up, down, strange or charm quark. In this experimental work we study the B^+ meson ($\bar{b}$u) and the B_s meson ($\bar{b}$s) [2]. Bottom quarks are created in the initial hard scattering stage and retain their identity while traversing the medium they are in, thus recording information about its evolution. By comparing pp collisions (vacuum medium) with PbPb collisions (QGP), we can therefore use B mesons as probes to study the QGP properties. The goal of this study is to measure the B meson's cross section in PbPb collisions at 5 TeV and to study how the QGP affects the hadronization of the b quark.

The cross-section is given by:

$$\sigma = \frac{N}{\varepsilon \mathcal{A} \mathcal{B} \mathcal{L}} \quad , \quad (1)$$

where N is the signal yield, $\mathcal{L}$ the luminosity, $\mathcal{B}$ the branching fraction, $\mathcal{A}$ the acceptance and ε the efficiency. While N is measured from data, through the implementation of an unbinned fitting procedure in Section 5.1, ε and $\mathcal{A}$ are determined from Monte Carlo (MC) simulation, that is validated through the methods of sideband subtraction and sPlot, in Section 4.

2 The CMS detector

The Compact Muon Solenoid (CMS) is one of the four large experiments at the Large Hadron Collider (LHC). In Fig. 1 is represented a transversal slice of the detector and its layers. When the particles travel through the detector they leave signatures (deposits of energy) in different layers, which allows their identification. In Fig, 1 it is possible to identify these layers from inward to outward: the silicon tracker, which measures the positions of passing charged particles allowing their track reconstruction; the electromagnetic calorimeter (ECAL) and the hadronic calorimeter (HCAL), which measure the energy of particles); the solenoid, with a magnetic field of 3.8 T, that bends the trajectory of particles, allowing the measurement of their charge and momentum; and, the muon chambers, where the muons are detected, since they are able to penetrate dense materials. The most important subdetectors for this analysis are the silicon tracker and muon detectors, that are employed to trigger and measure the final

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LIP-STUDENTS-19-06

Search for exclusive top quark pair production at the LHC

Miguel Nobre Guerreiro[1,a]

[1] Instituto Superior Técnico, Lisboa, Portugal

Project supervisors: M. Gallinaro, B. Lopes October 2019

Abstract. As the heaviest particle in Standard Model, top quark is one of the current focuses of the LHC programme to search for new physics. This internship focused on the search for exclusively produced top quark pairs in the CMS experiment. In this project I performed a kinematic analysis of Monte Carlo samples of events in proton-proton collisions at a center-of-mass (CM) energy of 13 TeV, using information from the CMS central detector and the Precision Proton Spectrometer (PPS). By comparing the normalized distributions of exclusive $t\bar{t}$, inclusive $t\bar{t}$ and Drell-Yan regarding different kinematic variables, I could identify the ones that best discriminate signal from background and the respective selection cuts to apply. With this work, I was able to set the basis for a multivariate analysis that could be used on real data, through machine learning techniques.

Keywords: CMS, PPS, $t\bar{t}$, exclusive production, Monte Carlo, kinematic analysis

1 Introduction

1.1 Standard model and top quark

The Standard Model (SM) of particle physics is a theory which encloses all known fundamental particles and a description for the electromagnetic, strong and weak interactions that govern them. Developed in the early 1970s, it is considered a well-tested physics theory, in the sense that it has explained almost all collider experimental results and precisely predicted a wide variety of phenomena. Nevertheless, the SM displays some known limitations: on one hand, it only offers a description for three of the four interactions in the Universe (not accounting for gravitational force), and does not foresee a suitable candidate for dark matter; on the other hand, the CP violation described by the SM may be insufficient to account for the matter-antimatter asymmetry of the Universe. So, although the SM accurately describes phenomena within its domain, it is not seen as the complete picture, which thus motivates experimental searches for Beyond the Standard Model (BSM) physics [1].

Top quark is the heaviest particle described by the SM and it was discovered in 1995 [2]. Because of its large mass, it is a fundamental particle of special interest for being potentially more sensitive to SM deviations. Top quark

leptons with respect to jets, caused by the superior efficiency of trackers over calorimeters in CMS, which will be addressed in the following section.

1.2 Exclusive $t\bar{t}$ production

In a proton-proton collision, some of the quarks and gluons from one of the protons will interact with those from the other proton at high-energy, resulting, in general, in the disruption of the initial protons. In some collisions, however, these protons may interact by exchanging energetic photons, which combine producing new particles, while either one or both initial protons are kept intact, as shown in figure 1. These are called exclusive processes (or semi-exclusive, for when only one proton remains intact) [4]. This kind of process is rare but extremely interesting when the detection of the interacting protons is possible through forward detectors, which is the case at the CMS experiment, with the Proton Precision Spectrometer (PPS) described in the next section. The detection of the escaping protons allows the determination of their energy loss in the interaction. Thus, it makes possible the kinematic reconstruction of the system, despite the existence of Missing Transverse Energy (MET) due to the neutrinos in the W

Available on CMS information server **CMS AN -2019/219**

The Compact Muon Solenoid Experiment

Analysis Note

The content of this note is intended for CMS internal use and distribution only

03 October 2019

B meson production in PbPb data: signal extraction and MC validation

A.Pardal, J.Goncalves, J.Silva, N.Leonardo

Abstract

We study B mesons reconstructed in the PbPb data sample at 5 TeV collected by CMS during November 2018. The signal is extracted from the data sample using the sideband subtraction and sPlot methods. Results are compared against MC simulation. Differences are quantified through data/MC ratios, that form weights which are used to correct the simulation.

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