

Physics goals at the LHC: Looking forward and beyond opportunities with the LIP-CMS group

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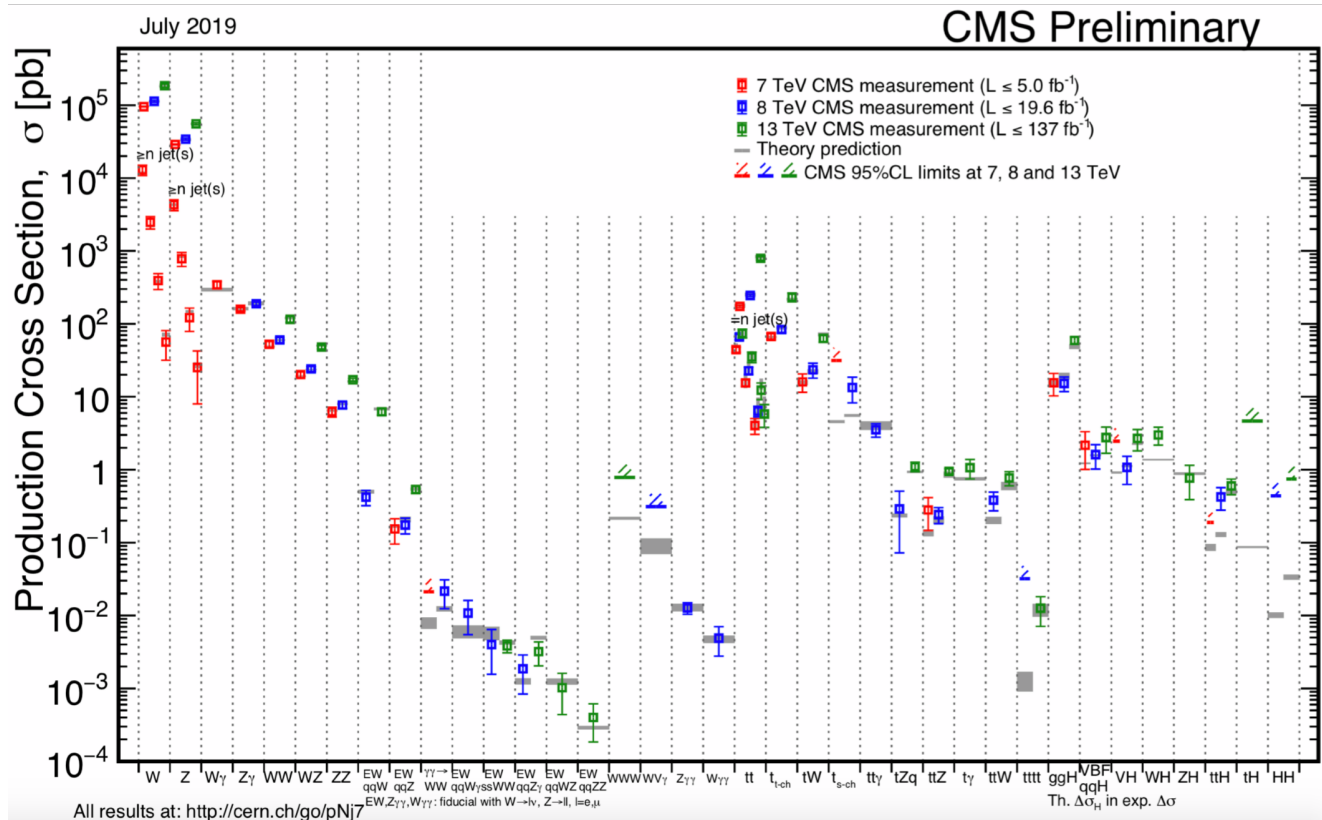
reserved.

LHC: from searches to precision

- A hadron collider at full steam
 - Reaching the energy limit
 - In Run3, collisions at 14(?) TeV
 - Large datasets
- Perform **precise** measurements and study **rare** processes
- Preparing for HL-LHC (2026 and beyond) with improved detectors
 - Several technological challenges ahead as complexity increases

Mapping the SM

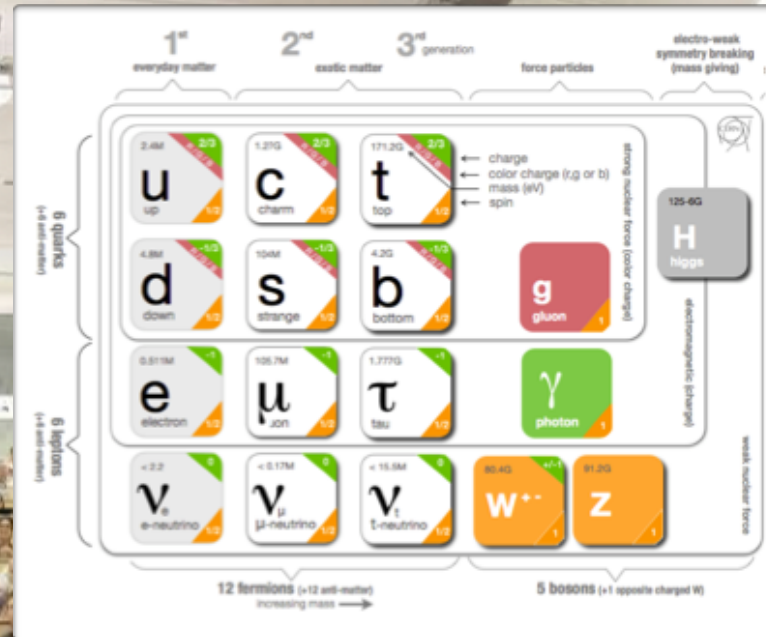
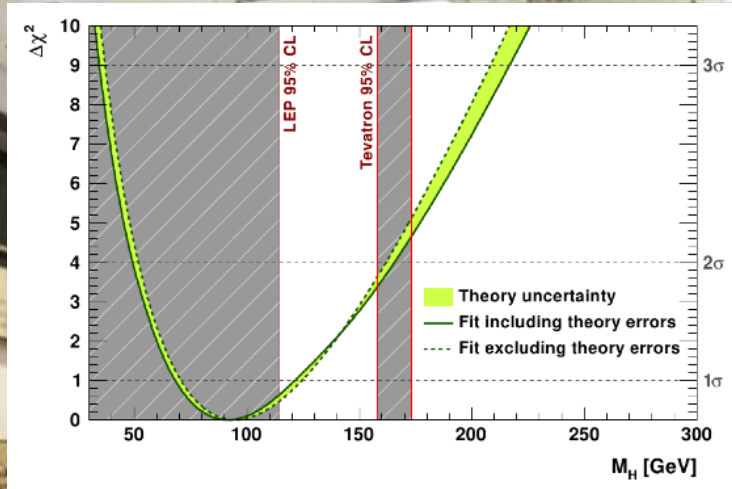
Many measurements during the first years of the LHC tested the SM to an incredible precision over several orders of magnitude!



SM is not complete: there are many unanswered questions

A significant discovery

Discovery of the Higgs boson: guided by clues of SM measurements



After the Higgs...

...we are in uncharted territory

- Data analysis
 - Tests of the SM, Higgs boson studies, searches for New Physics
 - R&D and detector upgrades
 - PPS and Timing detector
 - Involvement in running of the experiment
 - understanding, operation, direct involvement
- ⇒ There is a lot to learn

Tests of the Standard Model

M. Araújo, P. Bargassa, D. Bastos, R. Bugalho, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, B. Lopes, T. Niknejad, M. Pisano, K. Shchelina, J. Seixas, J. Silva, P. Silva, R. Silva, M. Silveira, G. Strong, O. Toldaiev, J. Varela

At the LHC we will continue testing the SM through **precise measurements** and **rare decays** studies:

- **Lepton Flavor Universality: top- and b-quark physics**

JHEP 02 (2020) 191

- **Forward physics w/ proton tagging: excl. processes**

JHEP 07(2018)153, MSc thesis, IST, Dec.2019

- **Heavy ion collisions: heavy flavor**

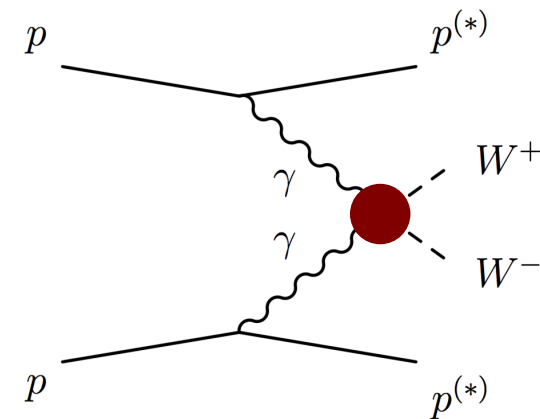
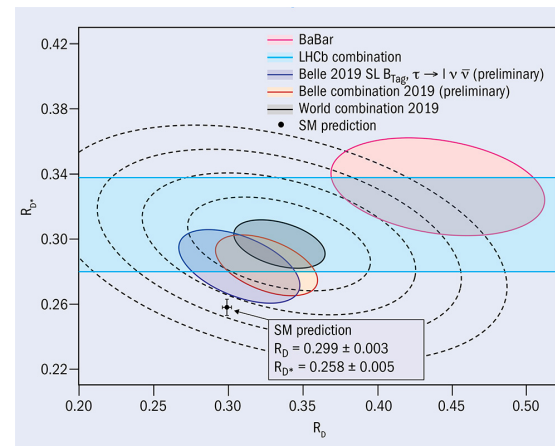
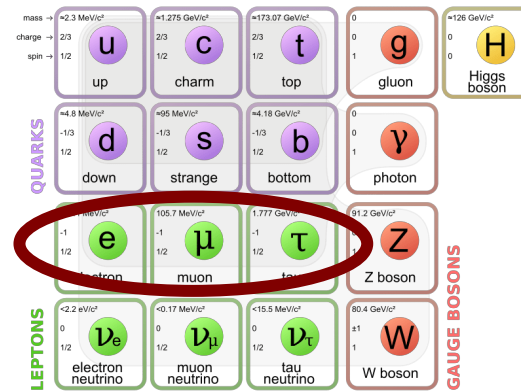
MSc thesis, IST, Nov. 2019

- **Rare decays: $B \rightarrow \mu\mu$, $B \rightarrow K^* \mu\mu$**

JHEP 04 (2020) 188, arXiv:1812.07638

- **Quarkonia: polarization studies**

PRL 124 (2020) 16, 162002



The Higgs boson and beyond

M. Araújo, P. Bargassa, D. Bastos, R. Bugalho, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, B. Lopes, T. Niknejad, M. Pisano, K. Shchelina, J. Seixas, J. Silva, P. Silva, R. Silva, M. Silveira, G. Strong, O. Toldaiev, J. Varela

The Higgs boson was discovered in 2012 and it is still a largely unknown particle. A detailed study of its properties may provide hints to the EWSB mechanism and possibly to New Physics.

Our studies in this area cover:

- **Higgs discovery & couplings:** diphoton final state

PLB 716(2012)30, JHEP 08(2016)045

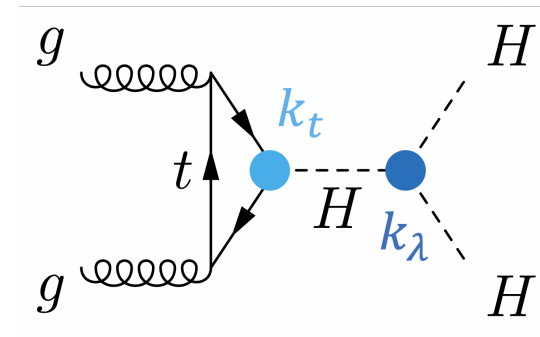
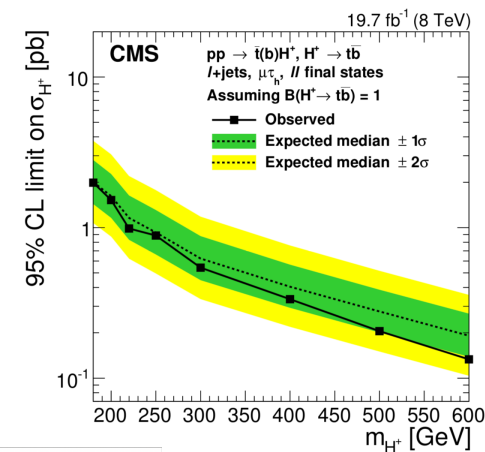
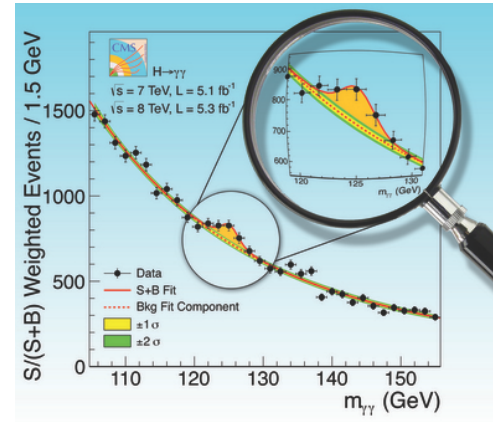
- **Charged Higgs:** if present, it would be inequivocal presence of BSM physics

JHEP 07(2012)143, JHEP 11(2015)018

- **Higgs Pairs:** allows measurement of self-coupling parameters (k_λ) with Machine Learning tools

PLB 778(2018)101, arXiv:1902.00134, CMS-TDR-020

- **Higgs rare decays:** couplings to light generations



Beyond the SM

M. Araújo, P. Bargassa, D. Bastos, R. Bugalho, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, B. Lopes, T. Niknejad, M. Pisano, K. Shchelina, J. Seixas, J. Silva, P. Silva, R. Silva, M. Silveira, G. Strong, O. Toldaiev, J. Varela

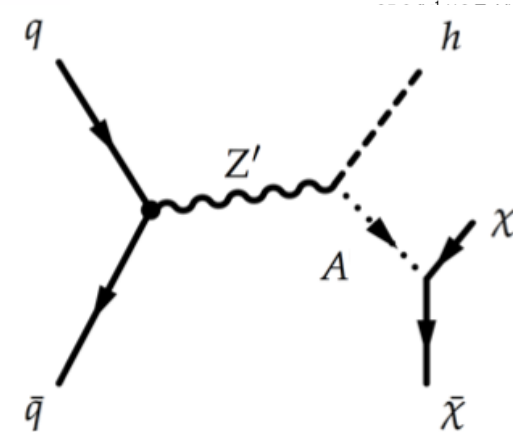
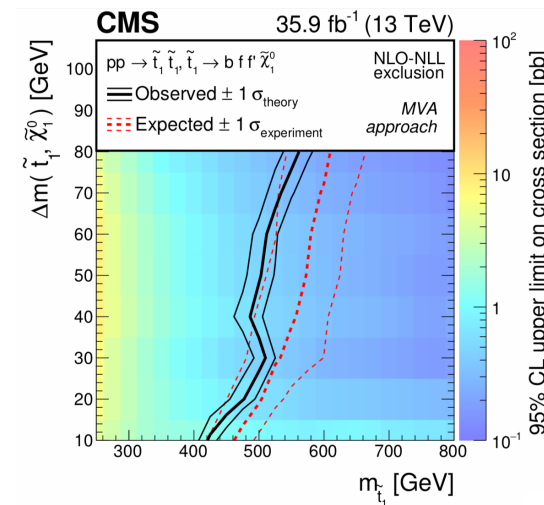
The SM has no apparent major problem. However, there are compelling reasons to believe the SM is an incomplete theory of Nature.

- **Supersymmetry**: exploring a compressed spectrum where mass difference btw stop and LSP is smaller than W boson mass

JHEP 09 (2018) 065

- **Dark Matter**: produced in association with the Higgs boson, only a few events, large MET

JHEP 03 (2020) 025



Detector Upgrades

M. Araújo, P. Bargassa, D. Bastos, R. Bugalho, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, B. Lopes, T. Niknejad, M. Pisano, K. Shchelina, J. Seixas, J. Silva, P. Silva, R. Silva, M. Silveira, G. Strong, O. Toldaiev, J. Varela

The HL-LHC will provide an integrated luminosity of 3000 fb^{-1} over 10 years of operation. It will present many technological challenges. We are preparing by developing new detectors and by upgrading the current ones.

LIP Contributes to

Calorimeter Endcap

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

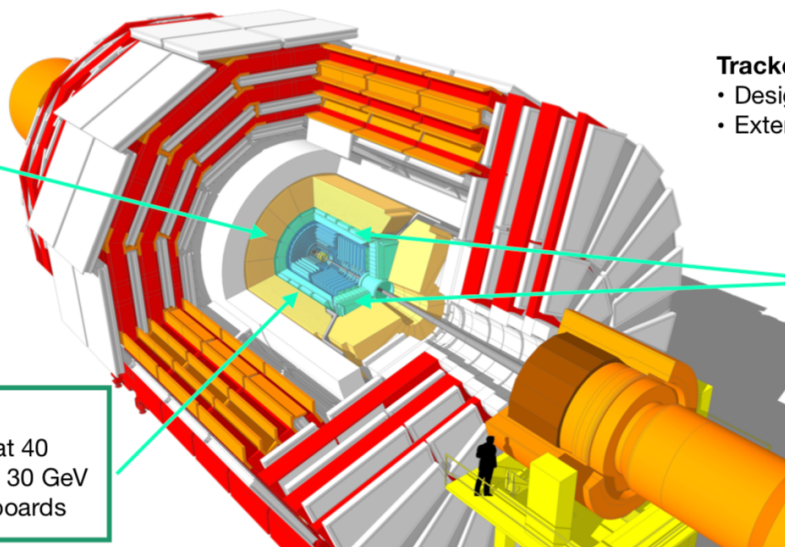
Muon systems

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \approx 3$

LIP Contributes to

Barrel Calorimeters

- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Tracker Si-Strip and Pixels increased granularity

- Design for tracking in L1-Trigger
- Extended coverage to $\eta \approx 3.8$

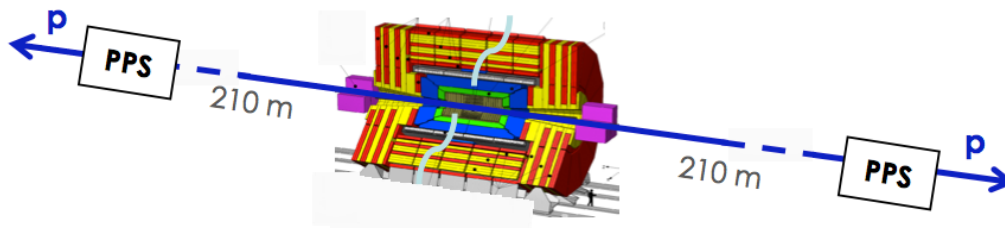
LIP Contributes to

MIP Timing Detector - MTD

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

L1-Trigger/HLT/DAQ

- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
- HLT output 7.5 kHz



LIP contributes to

Precision Proton Spectrometer
Detector design and physics prospects

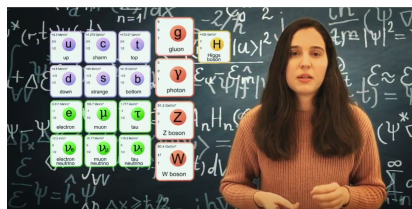
Recent MSc and PhD theses



Measurement of b-quark fragmentation fraction ratios at the CMS experiment: a key ingredient for the $B_s^0 \rightarrow \mu^+ \mu^-$ rare decay analysis

CERN-THESIS-2018-274, May 2018

Bruno Afonso Fontana Santos Alves



Probing the quark gluon plasma medium through B meson production measurements in PbPb collisions at the LHC

CERN-THESIS-2019-256, Oct. 2019

Júlia Manuela Cardoso Silva



Search for exclusively produced top quark pairs at the LHC

CERN-THESIS-2019-280, Dec. 2020

Beatriz Ribeiro Lopes



UNIVERSIDADE DE LISBOA
INSTITUTO SUPERIOR TÉCNICO



DEEP LEARNING METHODS
APPLIED TO HIGGS PHYSICS AT THE LHC

Giles Chatham Strong

arXiv:1902.00134, Mach. Learn. Sci. Techn.1 045006, soon in 2020



Universidade de Lisboa
Instituto Superior Técnico



Top quark physics and search for physics beyond the Standard Model at the Large Hadron Collider

JHEP 02 (2020) 191, soon in 2020

Author: Oleksii Toldaiev

Opportunities & Challenges

Plenty of **opportunities** ahead, both in technology and data science

- Will offer good jobs, either Academia or elsewhere

Challenges:

- Difficult challenges due to difficult problems

⇒ Active participation, dedication, and keen curiosity

Thank you!

- Interesting analysis topics available
- Strong involvement of students
- Master and PhD thesis projects



⇒ Join, your contribution will make the difference!