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Research Statement

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My research interests are related to experimental studies of collider particle physics. Since the start of my research career, I have been lucky to have the opportunity to work on an unusually wide range of particle physics topics: precise measurement of Standard Model (SM) processes, high-mass searches for the Higgs boson, phenomenological studies about di-Higgs production, and searches for displaced muons and exotic Higgs decays.
Also, I always associated physics analysis with detector responsibilities. I started my career working with the CMS Electromagnetic calorimeter, I contributed to test beams, and I am currently respnsible for the alignment of the CMS muom system. Finally, I have been selected to serve as manager for the alignment and calibration conditions of the whole CMS experiment.

Physics interests and experience

Heavy Higgs searches and SM measurements: I started my career as a Master student at Università of Rome La Sapienza searching for the Standard Model Higgs boson in the decay channel $H \to WW \to l\nu jj$ at the CMS experiment. Despite the very challenging final state (due to the presence of a neutrino) I showed that it is possible to improve the sensitivity of this final state by indirectly computing the neutrino momentum solving the process' kinematic. Also I took care of the selection optimization, the kinematic fit to the two jets to improve the W boson mass resolution, and I derived the limits on the Higgs cross section.
During my Ph.D. I shifted my interests into the precision measurement of SM processes. In particular I measured the pair-production of electroweak neutral bosons (ZZ) cross section in the leptonic decay channel: $ZZ \to ll\nu\nu$. This process is of particular interest due to its low cross section, and for its sensitivy to new physics beyond the Standard Model thanks to searches for possible triple gauge anomalous couplings ($ZZ\gamma$ or ZZZ). Also, very competitive constrains on the Higgs boson width can be obtained by the study of dileptons events from Z boson decay with high missing transverse energy. Among the several challenges from this analysis there is the data-driven estimation of backgrounds; this part has been very important due to the large Drell-Yan cross section, that has been estimated using a process that has similar jet multiplicity, underlying event, and pileup conditions: the production of prompt isolated photons in association with jets. Results of our work lead to a journal publication, and were presented at numerous international conferences.

Exotic Higgs decays: At present, the main focus of my interests is on Exotic decays of the Higgs boson, and in displaced muons.

I serve as contact person for the physics analysis: "A search for beyond the Standard Model light bosons decaying into muon pairs at CMS", where I led a group of graduates students and postdocs in a study that resulted in a public analysis (HIG-16-035), and that is currently targeting a paper where the whole 2016 dataset is analyzed. In Run-2 we introduced a couple of remarkable features in the analysis in order to further increase the sensitivity for the detection of new particles with intermediate to large lifetime. The first one is the development of a new low-threshold tri-muon trigger that removes constrains in the reconstruction of highly displaced muons and therefore increase the efficiency for the detection of dark photons that decay tens of centimeters away from the beam-line; the second is the increase in the effective region of search (fiducial volume) which was previously constrained to the 1st layer of the pixel detector (both central and forward region), in order to preserve high reconstruction and triggering efficiencies. Due to recent improvements in the reconstruction algorithms, we were able to double this volume maintaining the efficiency high. Finally, it has been improved the template fit for estimating the background contribution coming from standard model production of pairs of b-quarks, reducing the systematic uncertainty on the background estimation. These implementations improved considerably the quality and potential reach of the analysis.

Di-Higgs searches: I coordinate a collaboration with theorists from University of Massachusetts Amherst to search for heavy Higgs bosons decaying to pairs of light Higgs bosons in the H→hh→WWbb channel, using a novel technique (Heavy Mass Estimator) that allows full mass reconstruction of the mass of the heavy resonance. The use of a machine learning technique has been used in order to differentiate the signal from the Standard Model backgrounds. These studies result in the publication of the phenomenology paper: "Resonant Di-Higgs Production in the bbWW Channel: Probing the Electroweak Phase Transition at the LHC" (Phys. Rev. D 96, 035007 2017), where it has been proved the large improvement in terms of sensitivity obtained by applying the Heavy Mass Estimator technique to a final state with two neutrinos. I currently took the lead in performing this search on the CMS data collected in 2017, with the use of the Heavy Mass Estimator algorithm. The analysis in 2017 involves a parametric training that allows us to use a deep neural network in order to separate Drell-Yann and top-pairs production from the signal, training all signal hypothesis at the same time.

Detector work and leadership experience

In order to acquire a deep understanding of data taking conditions, the Ph.D. work included a contribution to the calibration of the CMS electromagnetic calorimeter (ECAL) using neutral pions produced in the proton-proton collisions. More precisely, the target has been to improve the previous 3% energy resolution in the ECAL endcap to the design value of about 1%. The framework I developed is the one currently used by the CMS experiment.
An additional topic developed during my Ph.D. is the use of a precise timing information in the CMS reconstruction algorithms. The high-luminosity period of LHC (HL-LHC) will exploit at maximum the LHC potential. One of the main challenges of this phase is the pileup (PU) of the signal caused by the high number of concurrent interactions per bunch crossing, that will increase from the averaged number of 27 (for 2016 data) to 200 (expected at HL-LHC). The increasing of the PU will be an issue for the trigger and the reconstruction, degrading jet and missing energy resolutions and all the isolation quantities. The impact of a precise hit time measurement on the reconstruction performance has been studied deeply, focusing in particular on occupancy cleaning, vertex reconstruction with time, pileup jets subtraction and jet cleaning.

Since my first year at Texas A&M University I have been the responsible for the track-based alignment of the CMS Muon system. The muon detector alignment is one of the signature contributions by Texas A&M group to support the CMS Muon detector operations, which has a large impact on all of CMS for sensitivity to physics with high p_T muons. Leading a team of two postdoctoral-fellows and three graduates students, we have not only maintained the alignment framework updated with respect to the continuously evolving CMS software, but at the same time we brought the alignment framework to another level of precision and stability, and the chambers position resolution has improved to ∼150-250 microns depending on their geometrical position.

Since 2016 I have been the muon system alignment representative in the Muon Detector Performance Group Office (DPGO), whose purpose is to coordinate and improve the communication about among the muon system, and to define new policies that simplify the detector performance and upgrades.
In September 2017 I have been asked to serve as Alignment, Calibration and Database convener (Alca/DB). This role is a L2 management position under the Physics Performance Dataset (PPD) group. This position involve the responsibility to coordinate all the activities related to production and consumption of detector conditions, assuring CMS to have a complete and coherent set of condition for the processing of the fundamental workflows of the experiment. This role demands the interaction with all CMS detector representative, planning ahead each reconstruction and simulation gen ration campaign, and a deep understanding of the CMS structure and organization.

Future Plans

The physics program at the Large Hadron Collider (LHC) had a remarkable start. Since 2012 the ATLAS and CMS experiments collected about 100 fb^{-1} of data that yielded a vast quantity of physics results, summarized in about 1000 publications in referred journals so far. The main highlights have been the observation in 2012 of a new particle of mass 125 GeV by the ATLAS and CMS collaborations identified as the Standard Model (SM) Higgs Boson, and the observation of the very rare decay $B_S^0 \to \mu\mu$ through a combined analysis of CMS and LHCb data.

Despite these major accomplishments, both ATLAS and CMS collaborations still did not provide yet any indication of the presence of Beyond Standard Model physics (BSM). Nevertheless, the absence of new physics could be seen as indication to where we should focus our attention in the future, reminding us that the quest for new discoveries is not uni-dimensional.
In particular, new physics could be hidden into exotic signatures that are easy to miss (as for instance displaced objects), or it could be accessible through precise measurements of SM parameters, or through the search for rare processes. In order to accumulate the integrated luminosity needed for these investigations, LHC will have to enter into his next phase in about 2024: High Luminosity-LHC (HL-LHC). In the second phase of the LHC physics program, the accelerator will provide an additional integrated luminosity of about 2500 fb^{-1} over 10 years of operation. This will imply two enormous challenges for the CMS detector (particularly in the forward direction): radiation tolerance, and to deal with an unprecedented in-time event pileup.
To meet these challenges CMS will need to undergo several upgrades. In particular the CMS experiment has decided to construct a High Granularity Calorimeter (HGCal), featuring a previously unrealized transverse and longitudinal segmentation, for both electromagnetic and hadronic compartments. This will facilitate particle-flow-type calorimetry, where the fine structure of showers can be measured and used to enhance particle identification, energy resolution and pileup rejection.

In particular, the HGCal is capable to associate a 50 ps time resolution measurement to the reconstructed energy. The precise time information will add a new dimentionality to particle reconstruction and identification algorithms, allowing additional mitigation of the event pileup.

I have ambitious plans for the future utilizing the unique knowledge I gained from my past experiences, and my farsighted view of LHC physics program. In order to establish a preeminent role in the CMS physics program I will move toward two different areas of research. First of all, I will lead the searches for rare physics processes as resonant and non-resonant di-Higgs production, which will gain relevance especially with the increase of the integrated luminosity collected by the CMS experiment. In parallel, I will contribute to the development of the reconstruction algorithm of the High Granularity Calorimeter (HGCal), with particular focus on the exploitation of its precise time resolution, which offers a unique possibility to mitigate pilup contribution at HL-HLC.

Physics Analysis

The discovery of a Higgs boson with a mass around 125 GeV by the ATLAS and CMS experiments fixes the value of the self-coupling λ in the scalar potential, whose shape is determined by the symmetries of the SM and the requirement of renormalizability. Direct information on the Higgs three- and four-point interactions will provide an indication of the scalar potential structure. Non-resonant Higgs boson pair production can be used to directly study the Higgs boson self-coupling. At the LHC, Higgs boson pairs are predominantly produced through gluon-gluon fusion via two destructively interfering diagrams. For this reason the destructive interference between these two diagrams makes the observation of di-Higgs production extremely challenging. Even in the most optimistic scenarios of energy and integrated luminosity at the future HL-LHC, the SM cross section for di-Higgs production in proton-proton collisions at $\sqrt{s} = 13$ TeV for a Higgs boson mass of 125 GeV is $\sigma_{HH} = 33.5$ fb at next-to-next-to-leading order in quantum chromodynamics for the gluon-gluon fusion process.
The existence of new-physics can modify the relation between the Higgs potential and di-Higgs production; for example di-Higgs production can be greatly enhanced in cases where the Higgs is composite rather than elementary. Also, extensions of the scalar sector of the SM postulate the existence of additional Higgs bosons. An explored scenario is the two-Higgs-doublet model (2HDM), where a second doublet of complex scalar fields is added to the SM scalar sector Lagrangian. In case the new CP-even state is massive enough (mass larger than twice the Higgs boson mass) it can decay to a pair of Higgs bosons. Models inspired by warped extra dimensions predict the existence of new heavy particles that can decay to pairs of Higgs bosons. Examples of such particles are the radion (spin 0) or the first Kaluza-Klein excitation of the graviton (spin 2).

Searches for Higgs boson pair production have been performed by the ATLAS and CMS experiments using LHC proton-proton collision data. Di-Higgs searches can lead to a vast topology of final states. Among those, the $HH \to WW(ZZ) \to bbll\nu\nu bb$ decay channel offer the largest branching ratios of the 125 GeV Higgs boson. On the other hand, the cancellation of momenta of two neutrinos does not allow to reconstruct the invariant mass of the heavy resonance, which substantially diminishes the LHC sensitivity to resonant di-Higgs production. In order to boost the sensitivity of a search in this final state, a novel technique called Heavy Mass Estimator can be used in order to estimate the mass of the heavy resonance. Using a likelihood-based method it is possible to scan the phase-space of the kinematic, determinating the most probably heavy Higgs mass. Such method has been proved to increase the sensitivity of this final state up to the level of other final states ($bbbb$, $bb\gamma\gamma$). Furthermore, there is still much room for additional improvement for this channel sensitivity. The likelihood obtained from the scan pf the phase space could be analyzed, and, in combination with the parametric training that uses deep neural network algorithms to separate signal from SM background, could potentially improve the background rejection (mostly from top pairs production).

Detector work
During its second phase the LHC will integrate 10 times more luminosity than in phase 1, posing significant challenges for radiation tolerance and event pileup on detectors, especially for forward calorimetry. As part of its HL-LHC upgrade program, the CMS collaboration is designing a High Granularity Calorimeter to replace the existing endcap calorimeters. It features unprecedented transverse and longitudinal segmentation for both electromagnetic (ECAL) and hadronic (HCAL) compartments. This will facilitate particle-flow calorimetry, where the fine structure of showers can be measured and used to enhance pileup rejection and particle identification, while still achieving good energy resolution.

The CMS HGCAL consist of an electromagnetic part called EE and two hadronic parts called FH & BH. The electromagnetic part will be 25 X_0 deep and will consists of 28 layers of silicon pad sensors as active elements with lead in a stainless steel envelope as absorber. The two hadronic parts are in total 8.5 λ deep with 24 layers and steel absorbers. As active elements, silicon will be used in the high $|\eta|$ regions and scintillating tiles with SiPM readout in the low $|\eta|$ region. With silicon pads and scintillating tiles, high granularity in transverse and longitudinal direction will be maintained throughout the calorimeter and will allow for particle flow analysis. High precision time measurement with better than 50 ps resolution on a cell level is aspired for vertex reconstruction and pile-up rejection.
Timing is of particular interest in data-taking period with high luminosity, because the number of proton-proton collisions in the same bunch crossing is expected to be very high. Timing could be exploited for the association of photons, electrons and jets to their collision vertices, for particle identification, or to reject energy deposits coming from pileup vertices. Timing could provide an alternative vertex determination, based on pure timing information, with a O(cm) resolution. This is particularly relevant in events with low track multiplicity (e.g. $H \to \gamma\gamma$), where the vertex cannot be precisely determined with tracking information. A time requirement can be also used to reduce the occupancy, removing the energy deposited in a time not compatible to the one of a particle coming from the hard interaction. This may have important consequences in many respects, as for instance reduction of event size, or improvement of photon and jet energy resolution. Finally, the timing information associated to an energy deposits can be used to add one dimensionality to the particle-flow algorithm.

Looking forward to hearing from you soon,

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