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FINAL REPORT FOR JULY 2015 – JULY 2016

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1 Accomplishments in the last period

This research group has worked on the following topics since July 2015:

1.1 Physics analyses

- **Search for supersymmetry in the all-jets final state using α_T :** One of the most promising discovery channels for new physics is the search for a missing energy signature in multijet events. To separate events with real missing energy from the overwhelming background of mis-measured QCD multijet events, we use a kinematic variable, α_T , which for dijet events is defined as the ratio of the E_T of the second leading jet over the transverse mass of the dijet system: $\alpha_T = E_T^{j_2}/M_T$. Graduate student **Lo** has worked on the analysis that lead to the publication of the final 8 TeV data with 18.5 fb^{-1} , performing the background estimation of $Z \rightarrow \nu\nu$ by means of data control regions based on γ +jets, as well as the calculation of the final multijet QCD background contamination in the signal region. The **PI** and **Lo** have also worked on the interpretation of the limits in SUSY parameter space. This publication focused on stop quark production in compressed scenarios when the stop and neutralino (the lightest supersymmetric particle) are almost degenerate in mass: $\Delta m = m_{\tilde{t}} - m_{\tilde{\chi}_1^0} < m_W$. In this case, the final states comprise the flavor changing process $\tilde{t} \rightarrow c\tilde{\chi}_1^0$, and the 4-body decay $\tilde{t} \rightarrow b\bar{f}\tilde{\chi}_1^0$ (where $f\bar{f}'$ are fermions from, for example, an off-shell W boson). Improved experimental acceptance for systems with compressed mass spectra can be achieved by requiring the sparticles to be produced in association with jets from initial-state radiation (ISR). The sparticle decay products from these systems can be Lorentz boosted to transverse momenta within the experimental acceptance if they recoil against a sufficiently high- p_T jet from ISR. This topology is exploited by searches that consider “monojet” + E_T final states. We have proved that the α_T analysis is highly competitive in the monojet-like search involving the first decay, where the charm quark is lost, and we rely on ISR to find the signature. Additional interpretations are provided in stop pair production modes with the decays $\tilde{t} \rightarrow t\tilde{\chi}_1^0$ and $\tilde{t} \rightarrow b\tilde{\chi}_1^\pm \rightarrow bW^{\pm(*)}\tilde{\chi}_1^0$.

Lo is one of the main developers of the new code used for event reconstruction and selection in the 13 TeV analyses (PAS-SUS-15-005 and PAS-SUS-16-016). He continues to be in

charge of the characterization of the γ +jets control sample and others for the evaluation of the different electroweak backgrounds. In addition, he has developed the code to apply the “*b*-tag formula method” to estimate the number of events with different number of *b*-tagged jets in the final selection, without having to directly cut the simulated samples (which often yields only a handful of Monte Carlo events in high H_T regions). This improvement will enhance our sensitivity in highly *b*-enriched bins by 20%.

- **Measurement of the $t\bar{t}$ differential cross section in CMS Run 2:** The **PI** and **Galanti** together with University of Rochester **Prof. Demina** and postdocs **Verzetti** and **Hindrichs** have analyzed the 2015 and 2016 data to measure the differential top-quark pair cross section in the ℓ +jets final state. We have now produced several preliminary results and have a publication with 2.3 fb^{-1} (CMS-PAS-TOP-16-008) in internal CMS review. The $t\bar{t}$ production cross section is measured in the lepton+jets channel as a function of transverse momentum p_T and rapidity $|y|$ of the top quarks; p_T , $|y|$, and invariant mass of the $t\bar{t}$ system; and the number of additional jets. The results are compared to several generators and parton-shower predictions by performing unfolding to the parton level and to the particle level. In general, the measured cross sections are slightly lower than predicted, but are compatible with the expectation. The measured distributions are in agreement with the predictions of the event generators with some exceptions in the $p_T(t\bar{t})$ and $M(t\bar{t})$ distributions. The measured p_T of the top quark is softer than the prediction by most NNLO generators, confirming a previously observed trend in the 8 TeV data.

This is an important measurement to validate the Monte Carlo predictions at 13 TeV and search for deviations in the SM that would affect the production and kinematics of top quarks. In addition, a thorough understanding of the $t\bar{t}$ production and kinematics will help us in the search for SUSY in the all-hadronic final state, where $t\bar{t}$ is one of the main backgrounds. Every analysis searching for new physics with large H_T will benefit from a comprehensive characterization and understanding of the $t\bar{t}$ background in Run 2.

- **B-physics leadership:** **Galanti** was a L3 convener, responsible for the “Rare Decays” working group of the B-Physics PAG. He has finished editing the B-physics section of the CMS Phase-2 Upgrade Technical Proposal, he has overseen several analyses including the $B_s \rightarrow \mu\mu$ search and also the B-physics performance studies for the Phase-2 CMS upgrade. In September 2016 he has started his new role as B-Physics PAG convener (a L2 position), overseeing the whole physics group.

1.2 Hardware, operations and upgrade

- **CMS HCAL operations:** **Galanti** was in charge of refurbishing and commissioning the calibration laser of the Hadron Calorimeter (HCAL) of CMS for Run 2. From September 2015 until September 2016 he was the HCAL Operations coordinator (a L2 position within CMS). He was in charge of the daily running of the detector and leading a group of around 50 physicists in day-to-day operations.

Lo led the Prompt Analysis group, composed of around 8 students and postdocs in charge of studying offline any possible misbehavior detected by the operations team, and providing fast insight in any problems that may occur with a particular run of data. In particular, he has been in charge of monitoring the alignment and correct timing of the HCAL trigger decisions. The **PI** is now leading the group since January 2016, and working on software updates for the new readout electronics.

- **CMS HCAL detector upgrade:** The **PI** is working on studies of trigger primitives generation with the updated HCAL detector and electronics for Phase 2. The goal is to optimize the triggering decision and provide the most accurate information to improve jet energy resolution at level 1, balancing the number of bits available in each trigger primitive. Several combinations of layer's depth information, compression, and linearization algorithms have been tested in this framework. This work is carried out within the Trigger subgroup of the HCAL Detector Performance Group, and although based on the future electronics of the HCAL, it is also useful for the current configuration and to make optimal trigger choices during commissioning. The **PI** is also mentoring several students from other Universities in this group.

In addition, the **PI** has collaborated with University of Rochester **Prof. Bodek** to test different methods to make radiation-hard scintillators for the end-cap calorimeter solution in CMS for Phase 2.

2 Composition of the research group

Dr. Galanti joined the group in October 2014. Mr. Lo has been permanently based at CERN since the summer of 2014, he will defend his dissertation by May 2017. The following table lists the members of the research group and whether they were partially funded by this award (and how many months, until July 2016).

Name	Position	Funded (months)	Other support
Aran Garcia-Bellido	PI	fully (2)	
Mario Galanti	postdoc	fully (12)	COLA from USCMS
Lucien Lo	grad. student	fully (12)	COLA from USCMS

The salary of Dr. Galanti was covered fully by this grant. He receives COLA from USCMS for his service in the HCAL operations. Lo's salary was provided by this grant. He receives COLA from USCMS for his service in the HCAL operations.

2.1 Expected transitions in the group

Mr. Lo will graduate in the Spring 2017 and his work on the α_T analysis will be carried on by Mr. Colin Fallon, a new graduate student who has spent this summer at CERN, and just passed his preliminary exams.

3 Publications with significant contributions from this research group

1. "Measurement of differential cross sections for top quark pair production using the lepton+jets final state in proton-proton collisions at 13 TeV." CMS-PAS-TOP-16-008. To be submitted to Phys. Rev. D.
2. "A search for new phenomena in final states with one or more jets and missing transverse momentum with the α_T variable at 13 TeV." CMS-PAS-SUS-15-005. To be submitted to EPJC.
3. "Search for new physics in final states with jets and missing transverse momentum in $\sqrt{s}=13$ TeV pp collisions with the α_T variable. CMS-PAS-SUS-16-016. Preliminary result for ICHEP.

4. "Search for top squark pair production in compressed-mass-spectrum scenarios in proton-proton collisions at $\sqrt{s}=8$ TeV using the α_T variable." <https://arxiv.org/abs/1605.08993>. Submitted to Phys. Lett. B
5. "Differential $t\bar{t}$ cross section in the ℓ +jets channel at $\sqrt{s}=13$ TeV." CMS-PAS-TOP-15-005.

4 List of contributed internal notes

1. "Search for supersymmetric top quarks in pp collisions at $\sqrt{s}=13$ TeV with jet substructure tools." A. Garcia-Bellido, L. Lo *et al.* CMS AN-2016/263.
2. "Search for new physics in final states with jets and missing transverse momentum in $\sqrt{s}=13$ TeV pp collisions with the α_T variable." A. Garcia-Bellido, L. Lo *et al.* CMS AN-2016/161.
3. "Measurement of the differential $t\bar{t}$ production cross sections in lepton + jets final states at 13 TeV." M. Galanti, A. Garcia-Bellido *et al.* CMS AN-2016/020.
4. "HCAL Prompt Feedback Group Studies in Run2." L. Lo *et al.* CMS DN-2016/007.
5. "Inclusive WIMP searches using alphaT in final states with jets and missing transverse momentum at $\sqrt{s}=13$ TeV pp collisions." A. Garcia-Bellido, L. Lo *et al.* CMS AN-2015/279.
6. "L1 jet-trigger prefiring studies with 2015 data." L. Lo *et al.* CMS AN-2015/278.
7. "Measurement of the $t\bar{t}$ differential production cross section in semi-leptonic decays." M. Galanti, A. Garcia-Bellido *et al.* CMS AN-2015/153.
8. "Measurement of radiation damage of CMS Hadron Endcap (HE) scintillator tile/WLS fiber elements observed during LHC Run2 in 2015." M. Galanti *et al.* CMS AN-2015/270

5 Invited presentations at international conferences

1. May 2016. A. Garcia-Bellido: "Top quark production results from CMS." Pheno 2016. University of Pittsburgh, Pittsburgh, PA.
2. May 2016. A. Garcia-Bellido: "Searches for stops and sbottoms in CMS." Pheno 2016. University of Pittsburgh, Pittsburgh, PA.
3. October 2015. A. Garcia-Bellido: "First top quark results from CMS at 13 TeV." Brookhaven Symposium: Great expectations, a new chapter. Brookhaven National Lab, Upton, NY.