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CMS Level 1 Trigger Rate Upgrade for Heavy Ion Collisions

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Contents

1 Introduction

Relativistic heavy ion collisions allow experimental studies of quark-gluon plasma (QGP), the equilibrated high temperature state of de-confined quarks and gluons. At the Large Hadron Collider (LHC), the abundant production of hard probes such as vector bosons, heavy quarks, jets and quarkonia produced in the highest energy heavy ion collisions has opened a new era in the characterization of QGP, providing new information on initial state properties, parton energy loss and color screening. The capabilities of the Compact Muon Solenoid (CMS) detector in the detection of high momentum photons, electrons, muons, charged particles and jets have proven to be a unique match for the opportunities at the LHC. A key aspect of this success has been the convergence of detector needs for precision measurements in pp discovery physics in a high luminosity, high pileup environment and for QGP studies in the high multiplicity Pb-Pb collisions. This convergence has allowed CMS to adapt a large number of new analysis techniques to studies of heavy ion collisions, such as particle-flow jet reconstruction, studies of jet substructures, lifetime fits for secondary J/ψ studies, b- and c-tagging of jets, missing p_{T} measurements of W production and energy flow in dijet events.

The full power of these and other techniques will be exploited in future heavy ion studies beginning in 2018 and Run III, when an increase in the collision energy to $\sqrt{s_{NN}} = 5.02$ TeV and an eventual increase in PbPb collision rate to as high as $\sim 30-50$ kHz will enhance the production rate of hard probes by more than an order of magnitude. In this high energy and high luminosity era, CMS will undertake precision studies of complex observables such as γ-, Z^0- and $W^{\pm}$-jet correlations, heavy flavor jet quenching, multi-jet correlations and the azimuthal anisotropy of high p_{T} jets and quarkonia. Recently, extensive studies of fully reconstructed heavy flavor mesons such as D^0 and B^+ in heavy ion collisions also show that CMS is ideally suited for the studies of heavy flavor production and heavy quark energy loss in the quark-gluon plasma.

The CMS trigger and data acquisition system is the key to achieving the ultimate high p_{T} physics reach in heavy ion collisions. Uniquely, the CMS trigger system only has two main components, the hardware based Level-1 (L1) trigger and the High-Level Trigger (HLT), which is implemented as "offline" algorithms running on a large computer farm with access to the full event information. The conceptual aspects of applying this system to heavy ion collisions, which are characterized by much lower rate, but much higher multiplicity than those encountered in pp collisions, were first developed by the US CMS HI group (see, e.g. [**?**]). The HLT trigger work formed the basis for our previous proposals to the DOE Office of Nuclear Physics. As we demonstrated in that proposal, triggering on high p_{T} probes for PbPb collision rates up to several kHz (i.e. the design value for Pb-Pb) is possible using event rejection solely or mostly at the HLT level. In the 2011 Pb-Pb run, this allowed a reduction of the event rate to storage by more than an order of magnitude compared to the collision rate, without prescaling the most interesting high p_{T} observables. In the 2015 Pb-Pb run, the heavy flavor meson triggers developed by the US CMS HI group from a previous DOE proposal was deployed for the first time. For instance, those triggers increased the high p_{T} D^0 meson statistics in p-p (Pb-Pb) collisions by a factor of 600 (20) which opened a new era for the precision heavy flavor physics in heavy ion collisions.

It has now become clear that the LHC will be able to significantly exceed the Pb-Pb design luminosity in future runs, possibly reaching up to 50 kHz already in Run III. This will place an even greater emphasis on the CMS trigger and DAQ system. The CMS during Pb-Pb collisions is being operated close to its hardware limit in term of readout rate (see sec. **??** for details). As a consequence, the CMS will not be able to benefit of the increased luminosity without any dedicated upgrade. In 2017, a new 4-layer pixel detector will be installed in CMS which will greatly improve the impact parameter resolution of the charged tracks. This is an uniquie opportunity to combine the capability of CMS for the studies of high p_{T} probes with heavy flavor program down to $p_{\mathrm{T}} \sim 0$, complementary to the physics goal of the O(100M) ALICE upgrade. Moreover, a stage-2 upgrade of the Level-1 trigger system will be commissioned for Pb-Pb data-taking. This requires improvement in the front end detector readout bandwidth in Pb-Pb ccollisions, as well as significant development on the trigger strategy for the data-taking in 2018 and beyond such that CMS could provide unbiased single track, heavy flavor meson, jet triggers, that are critical for the CMS physics program, and at the same time record a large statistics Minimum-Bias triggered sample which could be used to for the studies of low p_{T} heavy flavor mesons. This necessates the development of underlying event background subtraction for the stage-2 L1 trigger system and improvements in the detector readout to increase the maximum L1 trigger accept rate during the Pb-Pb data-taking period.

In this proposal, we will present the CMS L1 rate upgrade design and demonstrate that the planned upgrade delivers the needed capability to record heavy flavor meson and jets over a very wide kinematics range at the full delivered rate in high luminosity Pb-Pb runs in 2018 and beyond. This new system will need to be commissioned by 2017-2018, before the next heavy ion running period at the end of 2018, to make successful Pb-Pb data-taking possible. Section **??** describes the expected performance of the upgraded trigger for several examples of critical measurements, compared to the the limitations of the current system. The technical details of the proposed upgrade project are described in Sections **??** and **??**. The support projects needed to guarantee an efficient L1 rate increase are described in Sections **??**, **??** and **??**. Finally, the proposed schedule, management plan and the budget are described in Sections **??** and **??**.

2 Physics motivation

In this Section we discuss the physics performance of the upgraded L1 trigger system for the 2018 high luminosity Pb-Pb run using three examples of measurements with rare probes. The performance of the upgraded system, which uses background subtraction for L1 event rejection and provides access to the full expected luminosity of 3 nb^{-1} is compared to that of the current system. These examples illustrate the large improvements in statistical precision afforded by the improved ability to select jet events and high p_{T} particles with stage-2 L1 trigger upgrade during high luminosity Pb-Pb collisions.

Below we discuss a selection of measurements which exploit the future high-luminosity data sets to provide important insights into the parton energy loss mechanism and heavy flavor particle production:

1. The flavor dependence of jet quenching is an important test ground for various parton energy loss models. Compared to light quarks, heavy quarks are expected to suffer from smaller radiative energy loss when passing through the medium because gluon radiation is suppressed at angles smaller than the ratio of the quark mass M to its energy E [**?**]. This effect (and its disappearance at high p_{T}) can be studied using charged particles, heavy flavor mesons and b-jets.

2. Measurements of the charged particle and heavy flavor meson azimuthal anisotropy (v_2) at very high p_{T} give access to the in-medium path-length dependence of energy loss. The azimuthal anisotropy as a function of particle p_{T} also yields important information about the parton energy dependence of the energy loss. At the low p_{T}, hadronization of heavy quarks such as parton-to-jet fragmentation and the recombination of heavy quarks and light flavors has a significant impact on the magnitude of the heavy flavor meson v_2.

3. Studies of jet-heavy flavor meson correlation could give important insights into the parton energy loss mechanism and for the studies of medium induced radiation and medium response to the energetic heavy quarks.

These and other measurements rely on a sufficiently selective jet and heavy flavor meson trigger to provide access to the full delivered luminosity. At the same time, a large minimum-bias sample is needed in order to access to very low p_{T} heavy flavor mesons and to perform data-driven tracking and jet energy corrections. To illustrate the impact of the L1 rate upgrade, data collected during the 2015 PbPb run were used to estimate physics reach for a future high-luminosity run (assuming L_{int} =3 nb^{-1}) for these three physics cases.

2.1 Nuclear Modification Factors of Heavy Flavor Mesons

One of the proposed observables that reveal the flavor dependence of in-medium parton energy loss is the reduction of heavy flavor meson yield. This can be studied by measurements of nuclear modification factors (R_{AA}), defined as the ratio of the yield in nucleus-nucleus collisions to that observed in pp collisions, scaled by the number of binary nucleon-nucleon collisions. Theoretical calculations of R_{AA} for fully reconstructed D and B mesons are shown in Figure **??**. At low p_{T}, the production rate of heavy flavor meson in PbPb is sensitive to the elastic energy loss of the heavy quark, gluon shadowing effect in the nuclear parton distribution function. and the rate of recombination of the heavy quark and light flavors at the hadronization stage. At high p_{T}, the size of the suppression is sensitive to the heavy quark radiative energy loss in the pQCD based models. Precision measurement of the R_{AA} from intermediate p_{T} ($\sim$ 10 GeV) to very high p_{T} (200-400 GeV) could the pathlength dependence of the heavy quark energy loss and potentially to distinguish models based on AdS/CFT and pQCD.

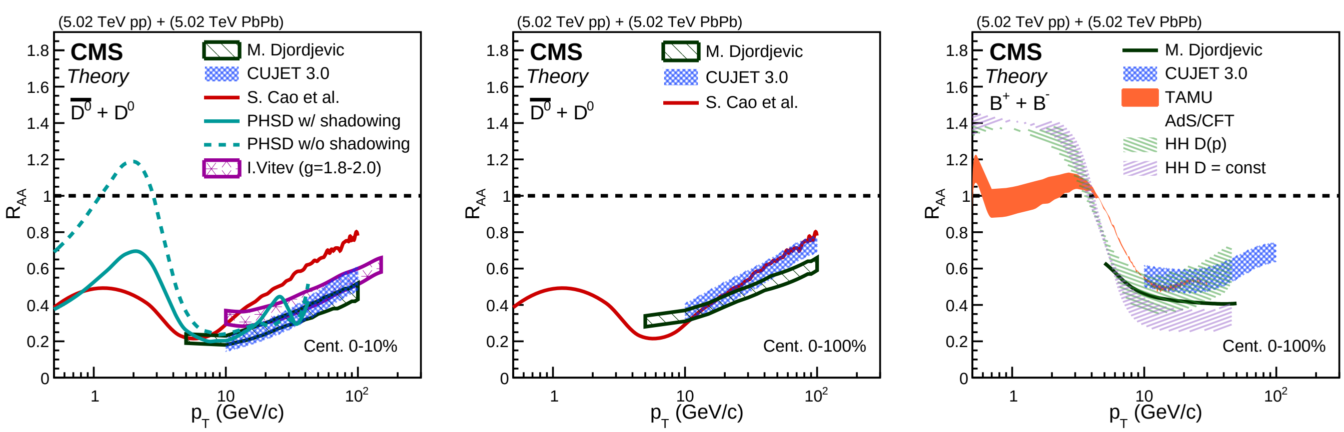

Figure 1: Theoretical calculations of nuclear modification factors of charged particles, D^0 and B^+ mesons.

It is also predicted that a significant fraction of the low p_{T} heavy quarks could hadronize via recombination with other quarks from the medium. These motive measurements of the R_{AA} from D^0, D^+, (B^+), D_s^+ (B_s) and Λ_c (Λ_b) which could provide crucial information about the interactions of the heavy quarks and the produced medium. Especially, the D_s and B_s measurements are sensitive to the strangeness content of the produced strongly interacting medium. Figure **??** shows the performance of $D^+ \to \phi\pi^+$, $D_s^+ \to \phi\pi^+$, $\Lambda_c \to pK^-\pi^+$ and $B^+ \to \bar{D}^0\pi^+$ reconstruction in the heavy ion collisions with the CMS detector, projected to the expected statistics to be collected with the L1 trigger rate upgrade. Significant signals of D_s^+ and Λ_c could be observed which enable the measurement of Ds and Λ_c R_{AA} for the first time.

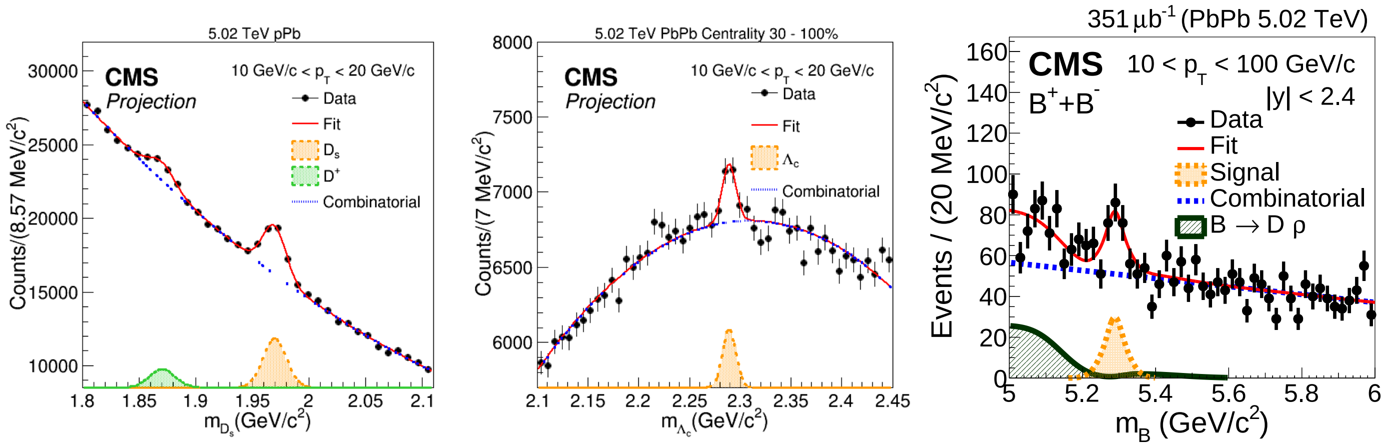

Figure 2: Invariant mass distributions

Figure **??** shows the expected performance with the data recorded in 2015 and the projected performance in 2018 and beyond. With the high statistics jet and heavy flavor triggered sample, the precision of the R_{AA} measurements at high p_{T} could be greatly improved by jet and heavy flavor triggered sample. At the same time, with the L1 trigger rate upgrade proposed in this proposal, the much larger minimum-bias sample enables CMS to perform these studies down to the very low p_{T} region. The expected precision of D^0, B^+ and D_s R_{AA} measurements from low p_{T} to high p_{T} could provide strong constraint on the theoretical models and the difference in the suppression magnitude between those mesons could be observed for the first time.

2.2 Azimuthal anisotropy of Heavy Flavor Mesons

Azimuthal anisotropy of hadrons provides information about their production with respect to the reaction plane (Ψ_n). At high p_{T} , the larger in-medium path-length of the mother partons emitted in the direction of the reaction plane leads to a stronger suppression of the yield due to jet quenching. Therefore, measurements of the v_n coefficients from Fourier expansion of the particle distributions $dN/d\psi$ are sensitive to path length dependence of the parton energy loss. At low p_{T} , a large v_2 (elliptic flow) signal is considered as an evidence for collective hydrodynamical expansion of the medium. Measurements of heavy flavor meson v_n could provide important information about the thermalization of the heavy quarks in the medium. Precision measurements of the v_n as a function of heavy flavor meson p_{T} could teach us how the azimuthal anisotropy of the light flavor partons contribute to the observed anisotropy through the recombination of heavy quarks and light quarks. As shown in Figure **??**, the predicted elliptic flow (v_2) signal covers a large range of values due to the difference in the treatments of in-medium parton transport and parton energy loss. Figure **??** shows the expected performance of elliptic flow (v_2) measurements with the data recorded in 2015 and the projected performance in 2018 and beyond. The new precise data will be able to constrain various components of the theoretical models, to determine the heavy quark diffusion coefficient in QGP, and to reveal flavor dependence of the parton energy loss.

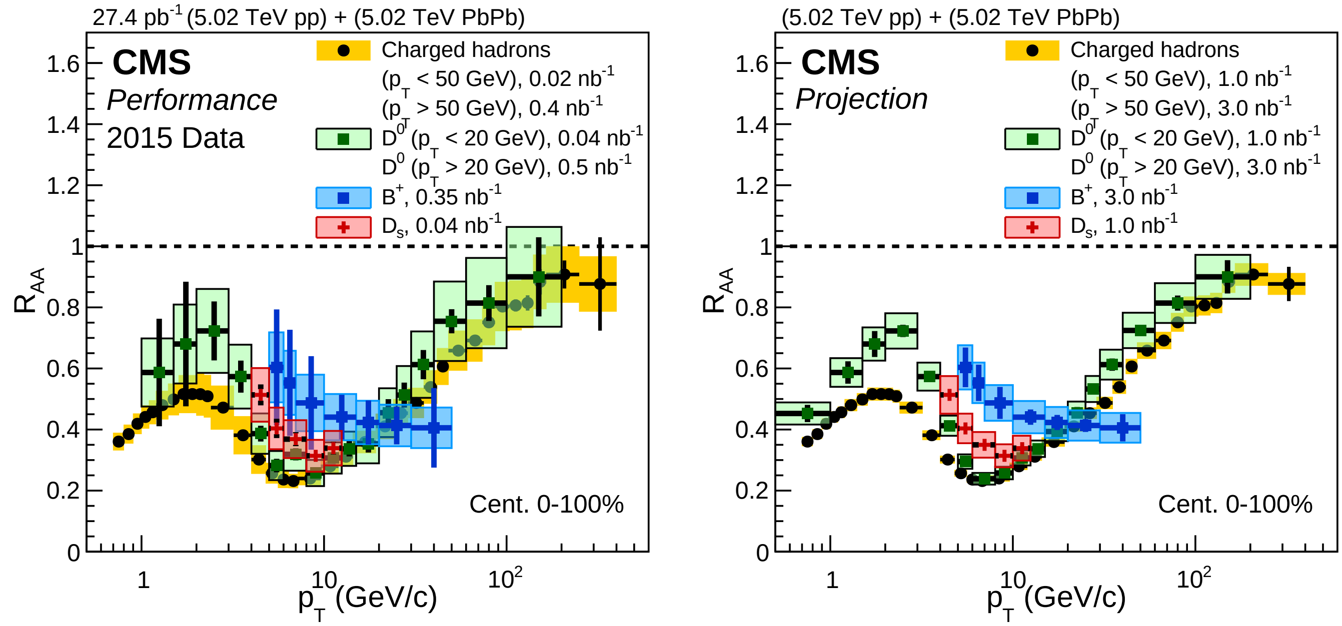

Figure 3: Nuclear modification factors of charged particles, D^0, D_s and B^+ mesons with 2015 data (left panel) and the statistics expected with L1 trigger rate upgrade.

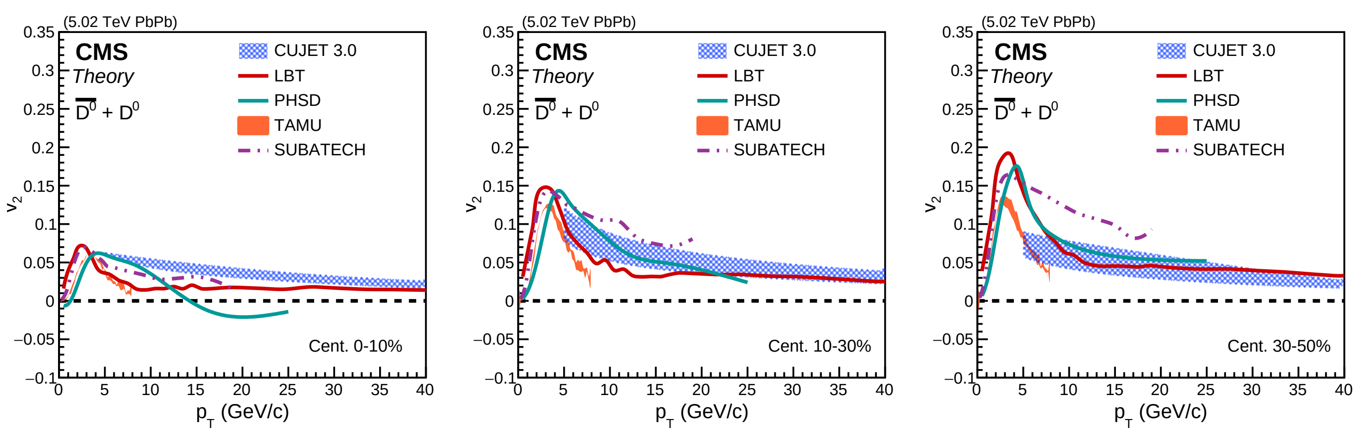

Figure 4: Theoretical calculations of v2.

2.3 D^0-Jet and D^0-hadron correlations

[To be updated]

CMS has published jet-hadron and jet shape and dijet missing transverse momentum measurements which showed a significant modification of the angular structure of the jets. Significant amount of energy is transfered

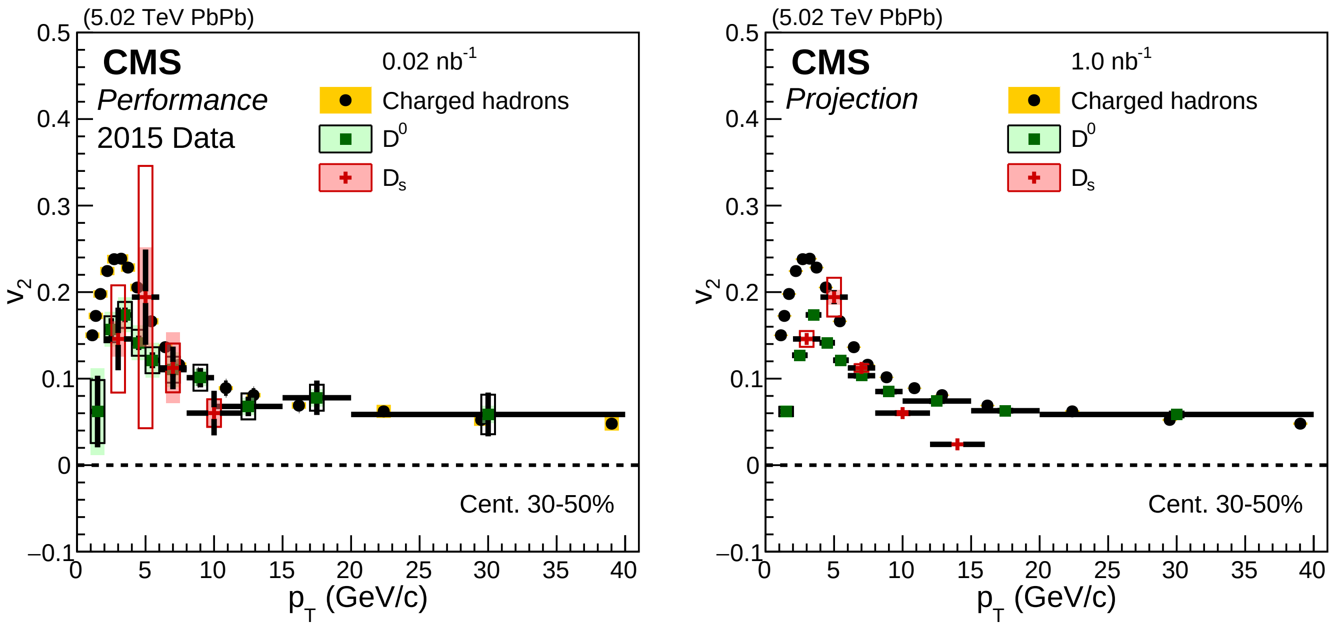

Figure 5: V2 measurement.

to very large angle with respect to the jet axis. Studies of D^0-jet and D^0-hadron angular correlation are sensitive to energy loss mechanism.

2.4 Summary

The current and projected physics performance of various measurements are shown in Table **??**. With the proposed works on the stage-2 Level 1 trigger upgrade and detector readout, the kinematic range covered by CMS could be greatly increased and many more observables which are not yet accessible with 2015 data will become feasible for the first time with the data taken in 2018 and beyond.

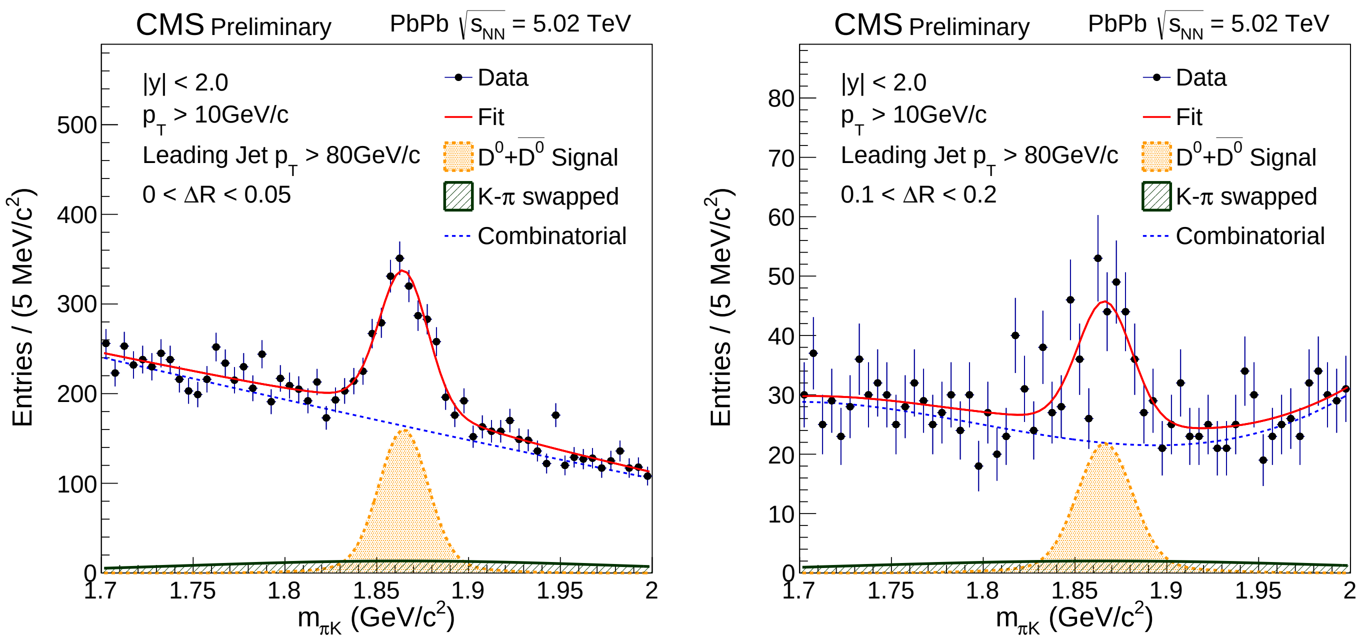

Figure 6:

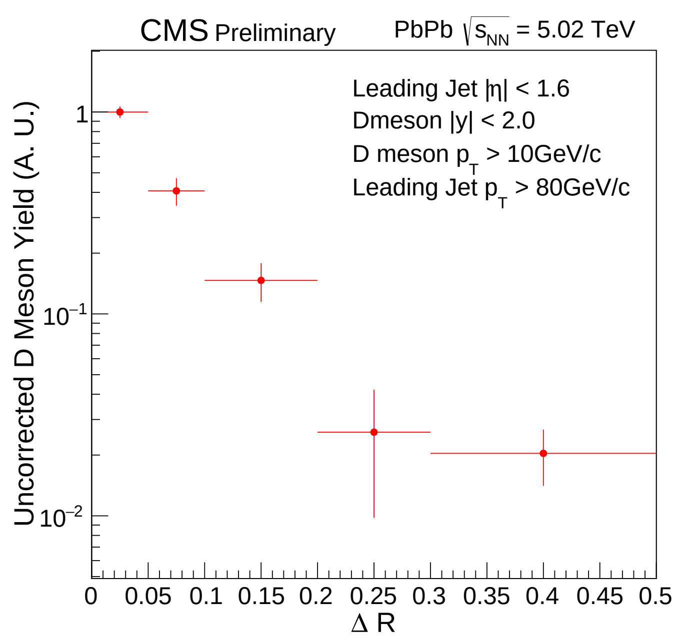

Figure 7:

Measurements of Current Pixel System and 2018 Pixel System				
	Current 0.04 nb^{-1} + Legacy Pixel System		**2018 PbPb 1 nb^{-1} + Pixel Upgrade**	
Observables	p_T min	Statistical Uncertainty	p_T min	Statistical Uncertainty
$D^0 R_{AA}$	2	15%	0.5 - 1	10%
$D_s R_{AA}$	~ 4	20%	< 4	4%
$\Lambda_c R_{AA}$	10	$> 20\%$	< 10	4%
$B \to D R_{AA}$	6	20%	2	10%
$B^+(D^0\pi) R_{AA}$	Not accessible		~ 4	
Low p_T c and b jets	Not accessible			
$D^0 v_2$ $(= 0.06)$	1	80%	0.5 - 1	18%
$D_s v_2$	Not accessible		~ 4	
$B \to D v_2$	Not accessible		~ 2	
$\Lambda_c v_2$	Not accessible		~ 6	

Table 1: Summary of the heavy flavor measurements with 2015 data and 2018 data with L1 trigger rate upgrade

3 Hardware Upgrade

3.1 Introduction

The CMS experiment is mainly designed to record high luminosity, high-PU proton-proton collisions events. However, with several detectors tweak/configuration changes, over the last several years, the CMS experiment has been able to record successfully also the high multiplicity Heavy-Ions collisions delivered by the LHC. As discussed already in previous proposals, the main changes required to allow CMS to operate in HI environments could be summarized as follows:

- A dedicated silicon pixel Front End Device (FED) firmware for high multiplicity environment. The overall FED data flow has been re-designed changing the readout schema of the input links and a redistribution of internal buffers.
- The silicon tracker zero suppression was bypassed and all the channels information were forwarded to the CMS DAQ system. The Zero Suppression was performed in HLT. A new tracker FED firmware was also designed to reduce the event payload of $\sim 30\%$ without information loss. The reduction was obtained stripping out from the standard dataformat unused information.
- DAQ reconfiguration / rebalance to deal with big data volumes and high throughput. In standard p-p collisions operation, an average event size correspond to $\sim 1 - 1.5$ MB. During Pb-Pb collision operation, the average event size is at around 17 MB.
- The Level-1 trigger firmware was redesigned to perform a dedicated underlying event subtraction algorithm and to include specific HI algorithms.
- Significant adjustment in the overall CMS dataflow.

With the specific configuration described above, and with a series of other small adjustments not mentioned here, CMS was able to run smoothly during the 2015 Pb-Pb data-taking with an average L1 rate of ~ 10 kHz. Few hours of the Pb-Pb data-taking period were also devoted to explore the limit of the CMS in term of maximum L1 rate allowed. With the 2015 CMS configuration for Pb-Pb, the absolute L1 rate limit was observed of 12 kHz. In the next sections this limit as well as solutions to increase it will be discussed.

During the 2015 run, the collision rate was of ~ 20 kHz. For the 2018 Pb-Pb run it is expected an increase of collision rate up to ~ 30 kHz. Without applying any changes to the L1 trigger mix used in 2015, this extra factor would mean to operate CMS at above its limits with a significantly impact on the physics program. In addition, as discussed in the previous sections, it would be beneficial to also further increase the number on minimum bias events collected.

The CMS subsystems as well as their interaction with the DAQ have been studied and a series of bottleneck areas were identified. This proposal addresses these limitations. The goal is to increase the CMS readout rate to 30 kHz. It is however important to bear in mind that this proposal will focus only on aspects that will require hardware changes. The comprehensive series of tasks needed for the overall run preparation is not reported here.

3.2 Silicon Strip Tracker

In standard p-p collision operation, the tracker detector sends the full detector information to 439 Front End Devices (FEDs). They apply the common mode noise subtraction and the strip zero suppression. However the common noise subtraction algorithm implemented in the Tracker FEDs firmware doesnt allow compensation of the baseline distortion observed in presence of Highly Ionizing Particles (HIP) with the consequent potential loss of clusters associated to the interested readout chip named APV. Due to the stringent requirements on tracking for high multiplicity HI events, the cluster finding inefficiency propagates directly to the track finding inefficiency dependending on the centrality of the collision.

The solution adopted up to now was to bypass the tracker zero suppression implemented in the tracker FEDs and send the full detector information to the DAQ/HLT. A specific HI common mode noise subtraction and zero suppression algorithms were implemented as HLT process. However, this solution implies an heavy load on the links between the FEDs and the DAQ and on the DAQ itself. The links are based on S-Link technology and with a maximum speed of 200 MB/s. Some FEDs (connected to sensors in which higher multiplicity is expected) have duplicated links allowing a maximum of $\sim$ 400 MB/s per FED. Considering that in average fragment size it is at 32 kB/event. The readout limit is at around 12 kHz. It was also already demonstrated that the FED itself is designed to sustain up to 520 MB/s of throughput. The limitation is then only coming from the links to the DAQ.

In agreement with the Tracker group, the only solution available to significantly increase the overall L1 rate is to modify the FEDs firmware including a more refined common mode subtraction algorithm accounting for baseline distortion. The output of the FED would be again zero suppressed allowing a reduction of the event size to DAQ of a factor of at leat 4. The system could then run at a L1 rage grater than 50 kHz.

The tracker FEDs are based on Xilinx Virtex-2 FPGA that is quite limited in term of on chip resources as well as clock frequency. This limitation implies that only algorithm designed with specifically for HI could be implemented in the FEDs FPGA. Due to the limited on-chip resources, it would not be possible to have a unique FW version allowing p-p and Pb-Pb operation. Two FW versions are then expected and used accordingly depending by the type of collision system considered.

In 2013 a specific HI zero suppression algorithm designed for high multiplicity environment and that would satisfy the FPGA constraints was designed offline and it is named baseline follower. Preliminary studies performed by the tracker and HI groups showed promising performance results for the algorithm. The first part of the project requires the detailed study of the algorithm offline. It will imply roughly 3 months of work and detailed clustering and tracking studies. Hardware feasibility studies are going to be performed in parallel by tracker engineers. During this phase the HI group should participate in providing the required information needed for the simulations. In the late spring/early summer 2017 the project will be handed over completely to the HI group where a developer will implement the actual algorithm in firmware. We estimate that the activity of coding will last 9 months. Afterwards, three months commissioning time including tests on the bench and test at P5 should be considered. This schedule should leave some resources available for the actual 2018 HI run preparation. At present the tracker group is focusing on the tracker operation during p-p collisions and the tracker upgrade project and a significant fraction of the work required for this project will need to fall under the HI group responsibility as mentioned above.

For completeness, we should also report that other possible strategies were studied/considered to increase the L1 rate without modifying the tracker FED FW. However, they were rejected being either too complicated to be implemented or being underperforming. The two other solutions envisaged were either to increase the number of links between the tracker FEDs and the DAQ or to reduce the data payload. The first solution appear to be too complicated adding extra $\sim$ 400 links. Apart the technical constraints, there would also not be enough time to install and commission the links during the EYTS. The second solution is to reduce the data payload. A FED firmware version implemented already in 2015 allows the reduction from 10 to 8 the number of bits readout by each strip ADC. However, this strategy would allow moderate increase of $\leq 20\%$ of the overall L1 rate at the cost of a reduction of the detector resolution/sensitivity.

3.3 ECAL

The ECAL off detector electronics (DCC) was designed to cope with a L1 rate of 100 kHz and an average event size of 2 kB/event. During p-p high-pu collisions the average event size is at around 1.5 1.8 kB. However, during Pb-Pb collisions, the average event size is of 15-20 kB (depending on the trigger mix) while the average event size for central PbPb collisions is of 34 kB. With so big event sizes, the L1 rate tolerated is up to 12 kHz. In the specific ECAL case, the hardware limits can be identified in two main areas: the link between ECAL DCC and DAQ, and the internal DCC speed. The links to DAQ are standard S-Link designed for 200 MB/s. For the 2017 run an upgrade of the mezzanine card on the DCC side including a bigger buffer is already planned. This upgrade should allow an increase of 10% in the total L1 rate. Also the increase of clock frequency on the mezzanine card is being considered. The second limit encountered is the actual DCC internal firmware speed. An increase of 50 % (maybe also 100 %) in speed can be achieved modifying the internal DCC firmware structure allowing the firmware to run at a higher clock frequency.

The ECAL group engineers gave already their availability to participate and supervise the project. However, the concrete implementation should be responsibility of the HI group. A person should be dedicated to the project for roughly 6 months.

In parallel to the DCC firmware development project another project adjusting the operational DCC parameters is started. An extra reduction on the event size can be obtained adjusting the Selective Readout and Zero Suppression threshold. The ECAL group is already studying the performance for p-p collision and the study should be repeated by the HI group for Pb-Pb collisions. On the same line, a part of the project consist also in reducing the ECAL event size (potentially up to 40 % reduction) reducing the number of samples collected for each event. At present the ECAL reads out 10 BX for each event and this number can be programmed down to a minimum of 6 BX. However, reducing the number of samples could have strong implication in the energy resolution. A complete study should be performed to understand how significant could be the effect of x-fit in Pb-Pb collisions and the consequently effects on the physics program. Considering the amount of work required for the offline studies mentioned above, we should allocate a person for one year to the project. Any of the two offline solutions mentioned above indeed require specific performance studies and also the implementation of CMSSW code for the eventually new configuration. Also the calorimeter calibrations should be re-derived.

3.4 Silicon Pixel Detector

A new silicon pixel detector including 4 layers is being installed and commissioned for the 2017 p-p run. The detector front end electronics and sensors are equivalent to the ones installed in the legacy detector. The whole off-detector electronics was re-designed and the FEDs are based on the latest Xilinx FPGA technology (Virtex-7). The new firmware designs takes already into account high multiplicity events. However, at present the performance of the FED has not been evaluated in HI multiplicity environment.

An electronics board with the scope to emulate the detector response was designed to perform the commissioning of the off-detector electronics. The test board is able to receive as input a set files with the hit positions and produces at its output link a response equivalent to the one of the actual FE electronics. The pixel group took the responsibility to use the test board and define as soon as possible the pixel operational parameters for Pb-Pb collisions. However, a person in the HI group will act a liaison person and provide the necessary information required by the pixel group to perform the emulation. The liaison person should also supervise the test phases to guarantee perfect adherence with the actual expected condition during collisions. The results of the emulations should be evaluated carefully and possible solutions identified in case the performances are below expectations.

3.5 L1 trigger

For the 2015 Pb-Pb run an upgraded L1 trigger system was designed. The Stage-1 L1 trigger was operated with specific HI algorithms. However, in the middle of 2016 the full trigger upgrade (referred as Stage-2 in previous proposals) was installed and commissioned. The upgraded trigger system has a new layer-1 and the single MP7 board layer-2 was replaced with 9 MP7 boards operating with a time-multiplexed architecture. Also the firmware was completely redesigned by the L1 team including a series of new algorithm specific to p-p collision operation.

It is mandatory for the 2018 HI run to port to the new system the specific HI algorithm. In the list we have a specific background subtraction, centrality triggers, single-track triggers and Q2 triggers. It was agreed with the L1 team that the stage-2 engineers would take care of the firmware implementation and commissioning. However, it will be responsibility of the HI group to conduct the performance studies of the algorithms and a specific description of the implementation. Furthermore some of the several tests on the bench or at P5 will be performed by the HI group. Also the compilation of the L1 and HLT menus will remain responsibility of the HI group. This work will be done as part of the of the CMS Experimental Physics Responsibility (EPR) the corresponds to the service work that should be provided by each CMS author.

3.6 Dataflow

In the previous sections of this proposal it was discussed the possibility of increasing the CMS readout L1 rate and the number of events on tape for Pb-Pb collisions. This strategy has a direct impact on several areas associated to data handling, data transfer, data storage and data processing. It is not part of the scope of this proposal to discuss the details associated to the work required in the different areas but the list of tasks that will be considered before the 2018 HI run is reported below:

- Optimize the DAQ operation for Pb-Pb collision. It include also the further increase of the bandwidth between HLT and Storage Manager. Also the buffering strategy of data at P5 is going to be studied
- Reduce the average RAW event size and create a new Analysis Object Data (AOD) reducing further the data volume of processed data.
- Adjusting the computing model for HI data to benefit at the maximum of the dedicated HI T2 computing center based at Vanderbilt University.

Considering the importance of the tasks of RAW events size reduction, few details are given here. With the actual configuration, it is indeed impossible to reduce the event size without creating a new event data content for RAW data. Only a fraction of the CMS detector could be stored in the event reducing the overall event size of a factor 2 or 3. This solution is definitively the most promising but it has significant drawbacks. All the information stripped from the event cannot be recovered. The new event content should also be general enough to foresee any future analysis of these data. At present the most promising idea is to have the HLT to produce two main data streams. The first data stream would contain events in standard CMS event data format while the second data stream would contain events where only a substet of the tracker and pixel FEDs informations are recorded. This latter data format will be used only for minimum bias events (or a fractions of the minimum bias events recorded) while the first data format will be used for all the other triggered events. The overall trigger mix decided in the future will define the exact size of the average data size but rough estimation indicated a reduction of ~ 30 % in the overall data size. Another solution being investigated is to have a similar approach to the one described above but to replace the specific minimum bias data data format with already processed objects. In this case, the HLT calculates tracks for minimum bias events and instead of outputting the RAW data format, the computed tracks objects are instead outputted. Preliminary studies demonstrate than this approach could reduce further the data size. However, the tracks reconstruction in HLT would be performed using online conditions of detector alignment and calibrations contemplating the possibility of have a lower tracking efficiency as well as an high fake rate.

4 Management Plan, Personnel, Schedule

The overall management of the upgrade of the tracker and ECAL for the 2018 HI run will be conducted within the existing management structure of CMS. MIT personnel supported by this request will be part of the two main groups and following the established management procedures within CMS. The leader of the project for the heavy ion physics will be Prof. Yen-Jie Lee of MIT. The responsibilities related of the heavy ion group in the various projects mentioned above will be the following:

- Detailed performance studies of the alternative algorithm for the tracker zero suppression. It includes the commissioning of the offline software dedicated to the local reconstruction code
- Re-design of the tracker FED firmware including the derivative follower algorithm
- Participate in the phases of validation, test and commissioning of the HI tracker FED firmware in the CMS experiment
- Performance sties on ECAL data reduction adjusting ECAL operational conditions. This activity implies also a significant re-design of the offline ECAL local reconstruction
- Adjust/re-design a part of the ECAL DCC firmware to increase overall rate. Also small hardare changes including power distributions/supply should be envisaged.

At present the performance physics studies required in the early phases of the project are carried by MIT graduate students under the supervision of Ivan Cali.

The firmware for the silicon tracker will be developed by a engineer bring part of the HI group and supervised by Ivan Cali of MIT. The project will be in strict contact with another people in the HI community and the Imperial College group.

The firmware for the ECAL DCC change will be carried out by Ivan Cali of MIT. The LIP group will provide support.

The schedule of the whole project/s is driven by the need to terminate the project/s by the beginning of fall 2018. Few months are left for online operation and final commissioning phases before the 2018 HI run. We identified the following milestones in the proposed schedule:

- Silicon Tracker zero suppression algorithm performance studies to be fineshed by May/June 2017;
- Silicon Tracker FW implementation to be completed by April 2018;
- Commissioning of the Silicon Tracker FED and corresponding software, September 2018;
- ECAL preliminar performance studied to be concluded by June 2017;
- ECAL calibration and corresponding offline software by August 2018;
- ECAL firmware implementation by March 2018;
- ECAL DCC commissioning finished by September 2018;
- Commissioning of the system in CERN/P5, September 2018;

5 Budget

In this proposal the overall budget for the MIT heavy-ion group contribution to the projects includes only the costs of manpower for the study, development and commissioning of the tracker and ECAL FEDs firmware. Other hardware upgrades and manpower for the 2018 Pb-Pb run preparations are put in the overal HI group service work budget (CMS Experimental Physics Responsibility the corresponds to the service work that should be provided by each CMS author) but not taken into account here (some support projects were mentioned in various sections of this proposal).

The full chain of development, testing and commissioning of Tracker and ECAL FW will happen at CERN. The test facilities in CERN B906 and B186 will be used in the early phases while the production system will be used for the final commissioning. The interaction with the hardware and the experienced developer is vital for the project. This is why the group of people involved must be stationed at CERN in Geneva.

The members of the team from the heavy-ion groups will consist of an engineer (or postdoctoral associate with firmware development background) and a MIT research scientist. The engineer will devote 12 months to the project while the MIT research scientist will devote 50% of its time starting in June until the end of October 2018.

The fully loaded off-campus base salary of the MIT research scientist is presently I don't have the number K\$. To compensate for the CHF/\$ exchange rate and the higher cost of living in Geneva we will provide Cost of Living Allowance to the scientist. The exact amount depends on the exchange rate at the time of payment but we estimate it to be about I don't have the number K\$. In addition there is some amount allocated for travel to and from Geneva. The costs is summarized in Table **??** and they all include MIT overhead. The cost of an engineer is estimated at around I don't have the number K\$ per year.

Year	Salary	COLA	Equipment	Travel	Travel	Total
	1 postdoc	1 postdoc		Per diem	Add. Travel	
7/1/13-6/30/14						

Table 2: ECAL and Tracker Upgrade for the 2018 HI Run funding profile, in K$

References

[1] Roland G (CMS Collaboration) 2007 *J.Phys.* **G34** S733–736 (*Preprint* `nucl-ex/0702041`)

[2] Dokshitzer Y L and Kharzeev D 2001 *Phys.Lett.* **B519** 199–206 (*Preprint* `hep-ph/0106202`)