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The Physics of ALICE HLT Trigger Modes

R. Bramm, T. Kollegger, C. Loizides and R. Stock,
{bramm,kollegge,loizides,stock}@ikf.uni-frankfurt.de,
Physics Department, University of Frankfurt/Main

Abstract

We discuss different physics cases, mainly of the ALICE TPC, such as pile-up, jets in pp and PbPb, Bottonium and Charmonium spectroscopy, and there corresponding demands on the ALICE High Level Trigger (HLT) System. We show that compression and filter strategies can reduce the data volume by factors of 5 to 10. By reconstructing (sub)events with the HLT, background events can be rejected with a factor of up to 100 while keeping the signal (low cross-section probes). Altogether the HLT improves the discussed physics capabilities of ALICE by a factor of 5-100 in terms of statistics.

1 Physics Motivation

The Physics of ALICE can be broadly grouped into two types of physics observables, which connect to the soft and hard sectors of QCD, respectively. Among the former group one finds the physics of bulk hadron production, multihadron correlations and interferometry, fluctuations of short and long ranges, resonance and string decay signals, as well as multistrange hyperons. Mostly these observables refer to aspects of nonperturbative QCD even if their initialization makes contact to the primordial partonic "transport" dynamics in which (at $\sqrt{s} = 5.5$ TeV per participant nucleon pair in PbPb collisions) perturbative QCD obvious plays a role, too. Pertubative QCD (pQCD) aspects dominate, however, in the second group of observables consisting of various aspects of jet and heavy flavour production. It is the main point of such studies to connect the initial dynamics during interpenetration of the interacting primordial hadronic ground state matter (supposed to be well understood from modern pQCD application to elementary $p\overline{p}$ collisions) to the ensuing parton cascade era. In that era the initial pQCD "seedlings" such as $b\overline{b}$ pairs or very energetic quarks and gluons may act as "tracers" of a dynamical phase that may approach the deconfined quark-gluon state envisaged in non perturbative Lattice QCD theory, before it hadronizes. The resulting final signals, e.g. jets, open charm and quarkonia should thus exhibit certain characteristic attenuation properties (suppressions, enhancements, quenching etc.) that might serve as diagnostic tools for the intermediate, non perturbative QCD era of near equilibrium partonic matter. It is clear from the above that all such observables also require systematic study of the more elementary *pp* collisions at LHC energy, in order to establish the base line physics - a further research focus of the ALICE experiment.

Clearly there is a coincidence of the "mostly soft" and "predominantly hard" QCD physics sectors of ALICE with relatively large, and small cross sections, respectively. It turns out that analysis with the former type of physics should require relatively modest event statistics, of a few 10^6 PbPb and about 10^8 pp collisions, whereas the systematic analysis of hard signals calls for an additional one or two orders of magnitude both in PbPb and pp. For example, inclusive production of jets with total transversal energy of up to 200 GeV, or of the weaker states in the bottonium family, is expected to occur (within the ALICE tracking acceptance) about once every 10^4 to 10^5 central PbPb collisions. It is the latter sector of ALICE physics which will be addressed below. Obviously some kind of on-line higher level trigger selectivity is being called for, in order not to be drowned in excessive demands placed both on DAQ bandwidth and off-line data handling format.

More specifically, ALICE differs from the other LHC experiments by its insistence on microscopic track by track analysis of the events, both in the central barrel (tracking from the ITS through the TPC and the TRD into the outer TOF layer and the photon array) and in the dimuon spectrometer. Calorimeters with a more summative output are absent in this basic design although an augmentation, by an electromagnetic calorimeter, remains as an upgrade option of special interest for jet spectroscopy. The consequence of the insistence on single track resolution leads to a raw data flux (after on-line zero suppression and Huffman compression in the digital front end electronics) amounting to about 40-80 Megabytes in a central PbPb collision, which presents us with up to about 20.000 charged tracks per event. Clearly, high statistics demands as associated with the above small cross section signals meet with excessive raw data volume calling for higher on-line selectivity based on track pattern recognition.

The required on-line selectivity can be accomplished with relatively modest computing and connectivity power, using an High Level Trigger (HLT) complex of about 1000 CPUs equipped with fast interconnectivity. A major part of the required processor power can be implemented already in the local data concentrator circuits (LDC) of the DAQ front end instrumentation that is devoted to the raw data flux from the ALICE barrel TPC detector which produces, by almost an order of magnitude, the predominating data input on the ALICE DAQ system. We shall illustrate below how the rarest physics signals (cross-section wise) provide for the most topologically distinct tracking signatures in the TPC subdetector - recognizable with relatively modest CPU-networking effort. We thus describe the physics cases motivating on-line HLT trigger schemes based on on-line tracking of the ALICE TPC output. Further refinement may result from calling in early time information of the ITS and TRD systems. The dimuon-forward spectrometer works outside the acceptance of the barrel detectors. Its HLT requires separate consideration but is of minor format as compared to the TPC HLT. The following sections describe the raw outline of an HLT system that will cope with an on-line degradation of a TPC event rate of 200 Hz for central PbPb collisions. There are three basic modes to such an HLT functionality. It may either generate selected candidate events according to the detected track topologies corresponding to certain specific trigger tasks. We will focus on jet spectroscopy at first, with a background suppression efficiency of between 50 and 100: thus a 200 Hz TPC event rate will generate 2 to 4 candidate events per second, which are written onto tape in full raw data format. Alternatively, the HLT system might reduce the full TPC sector readout to region-of-interest readout. E.g. reading out 2 sectors only (out of 36) in conjunction with a TRD-generated pre-candidate for a near back-to-back e^+e^- track pair resulting from bottonium decay will lead to an 18-fold compression of data flux. Finally, in later years of ALICE operation one may consider the option of employing the TPC HLT circuitry only insofar as on-line cluster identification is concerned, which then would be recorded by

DAQ instead of the full raw data arrays leading to an overall TPC data compactification by about 10 to 20. The latter mode will be employed in the next years by the RHIC experiment STAR, which resembles ALICE in layout. In summary there are three HLT modes: selective trigger, region of interest readout (filter) and global TPC raw data compression.

We have constructed and tested an HLT on-line tracking prototype at the RHIC STAR experiment (called L3 there) with 54 processors confronting the STAR TPC data format, which is about 10% of the expected event size for ALICE. Both the selective trigger and overall compactification (by a factor of 6 in this prototype case) modes work well. In particular, the on-line momentum and specific ionization resolutions of that device operating at a maximum rate of 50 Hz for central collisions of Au+Au at RHIC was shown to approach the off-line resolutions within about 20%. In later sections we shall extrapolate from this L3 to the ALICE HLT to obtain a guide line concerning ALICE HLT processing power demands.

In the following sections we shall at first specify the ALICE running conditions in terms of LHC luminosity with special emphasis on the TPC event rate, which is the slowest ALICE subdetector but creates, by far, the highest raw data flux. However, it also creates conditions of several superimposed events captured in one TPC output frame. That condition can be dealt with by selection of "clean events" in PbPb collisions (by lower level triggers) but only by an HLT on-line filter procedure in pp collisions at higher luminosity. This will lead to the proposal that data taking with inclusion of the TPC (there are other options in ALICE) can proceed at 200 Hz in central PbPb, and at 1 KHz in pp. With these options we arrive at an optimum TPC operation vis a vis the LHC luminosities.

Both options would create an event rate that is necessary for jet and bottonium spectroscopy, but can not be written directly to tape, because of the resulting raw data flux of about 10 to 15 Gbyte per second from the TPC alone. Further sections thus deal with the required expected HLT speed and selectivity in various modes. For illustration we shall mostly focus on high transverse energy jet spectroscopy, both in PbPb and in pp collisions. A consideration of other HLT trigger modes ends these sections of the document.

1.1 Running Conditions of ALICE

At the design luminosities concerning the ALICE experiment we encounter high interaction rates which are fully satisfactory for all observables of concern. However 8 KHz minimum bias PbPb rate as well as pp at 140 KHz would both create roughly 0.5 Terrabytes of potential raw data per second which we can not write to mass storage. This estimate already takes into account on-line zero suppression in all its high granularity subdetectors. Any kind of on-line intelligence is thus welcome to

1. maintain event rates appropriate for low cross section physics signals (charm and bottom spectroscopy, high E_T jets), which range down to one in 10^7 pp or to one in 10^4 PbPb events

   and to

2. reduce the bandwidths of DAQ processing and writing to tape, and the magnitude of data deposited and handled in mass storage. This is important as neither the taping speed has increased significantly (in a fashion resembling other component's "Moore's law" pattern), nor has the tape and robot media cost shown a marked decrease. One is eager, therefore, to keep these cost factors within reasonable bounds, while increasing the overall physics content of the raw data flow.

In view of point 2 it would be desirable to cut down to say 1.0 GB/s taping rate, i.e. to about 0.5% of the raw data rate corresponding to the luminosity limits. In order to achieve this we must employ any suitable method of front-end/DAQ intelligence, in particular with the data-intensive subdetectors TPC, TRD and Dimuon spectrometer. Such methods start with zero suppression and automatic, loss free data compactification (Huffman etc.), the latter expected to reach a compression by about two. These methods will not concern us here. Instead we concentrate on high level trigger- and filter-procedures (HLT) which are based on on-line tracking in large processor/switch/storage arrays placed at the front-end of the DAQ. We will comment on the physics driving such HLT-efforts, primarily, because we need first to assess the potential physics benefit, in order to conclude about the appropriate efforts in HLT and DAQ. The first topics that we choose to illustrate the expected HLT will be

1. Jet physics in pp (”first year” and beyond)
2. Jet physics in PbPb
3. Y spectroscopy in TRD and TPC, and
4. Event filter procedures for TPC/ITS open charm analysis

Some of these topics concern genuine triggers enabling us to scan upward of 200 Hz of PbPb and up to one KHz of pp, without exceeding a reasonable DAQ writing budget. In other cases the filter aspect dominates: recording the accessible physics with lower data volumes.

1.1.1 Technical Assumptions

At average luminosity of 10^{27} the minimum bias rate (assuming 8 barn total cross section) for PbPb is 8 KHz, of which we may label 1 KHz as ”central”. The bunch spacing is 100 ns, thus we get $1.2 \cdot 10^{-3}$ events per bunch crossing, i.e. very rarely we indeed get two events within the crossing time of about 100 ps. For KrKr at $5 \cdot 10^{28}$ luminosity and 4 barn the min. bias rate is 240 KHz, and the fraction of events unresolvable to our electronics rises to the 1 % level.

In pp we will have full LHC energy at first of $\sqrt{s}$=14 TeV (unlike in PbPb). We assume a luminosity of $2 \cdot 10^{30}$ here, which would lead to 140 KHz minimum bias rate for a 70 mbarn non-diffractive cross section. The above luminosity is already non-trivially low for the LHC overall running conditions (in combination with the maximal luminosities employed in the other experiments it would be simpler to run at far higher L). A lower luminosity for ALICE will be accomplished either by a different β^* or by de-tuning (or both). One concludes that we can not safely assume that the 2 σ size of the interaction domain (the ”diamond”) will initially be as low as 10 cm. Furthermore we will argue below that a further reduction of pp luminosity to the 10^{29} level is highly desirable: a challenge to LHC technique.

1.1.2 TPC Event Pileup and Rate

At the above event rates the TPC (90 μs drift time) has a significant double event fraction within the drift time already for PbPb which gets forbiddingly high for KrKr and CaCa at higher potential luminosities (no TPC physics possible). In pp at L=$2 \cdot 10^{30}$ we will have many (but smaller) events in each frame, displaced by the drift velocity of 2.8 cm/μs. More precisely the average fraction of PbPb double events in the TPC at 8 KHz minimum bias rate is [1-exp(-$2\tau_{drift} \cdot f$)] = 0.76 where we have taken 2τ because each TPC frame contains displaced tracks/events occurring both 90 μs before and after the trigger. This effect is specific to the TPC as all other subdetectors have drift - or integration times of up to 5 μs only. The "clean" minimum bias PbPb event rate thus shrinks to 1.900 Hz, the central rate to 240 Hz as far as the TPC is concerned; both at L (average)=10^{27}. This limitation of useful event rate roughly coincides with two other TPC limitations, the maximum possible TPC gating frequency (now estimated to be about 1 KHz), and the maximum data transfer rate from the TPC front-end electronics to the HLT/DAQ complex as implied by the 216 DDL links, whose individual bandwidth is assumed here to amount to 150 MB/s. Estimating a "clean" central PbPb event to contain 66 MB after zero suppression and a flat distribution of data traffic over all the TPC-DDLs we would get a maximum event transmission rate of 400/s. However, we already get into double events with about 100 MB event size this way, and, furthermore, the traffic distribution may not be flat over all DDLs. Thus we take about 200 Hz as a, perhaps preliminary, technical limit for "clean" central PbPb collisions and about 400 Hz for min. bias for any ALICE data taking mode involving the TPC. The HLT system will thus be presented in a version that copes with the corresponding raw data input of up to about 15-20 GB per second in PbPb collisions.

1.1.3 TPC Pileup in PP

In pp running at L=$2 \cdot 10^{30}$ and $\sqrt{s} = 14$ TeV the TPC physics gets quite challenging [3]. At 70 mb we get 140 KHz min. bias event rate. From prior and post 90 μs to the trigger 25 events fall into one TPC frame which are on average half-complete. Average spacing in time is about 7 μs but note that the events are not therefore ordered in drift distance because of the variation of the primary vertex position which will randomize distances, perhaps even inverting the ordering. This influences the capability to identify the sub-event that belongs to the trigger, by means of on-line tracking in the HLT leading to an output to DAQ that contains the relevant sub-event only (HLT filter mode).

The TPC data flux per event arising in a situation with 25 half-complete min. bias pp collisions at $\sqrt{s} = 14$ TeV is estimated to be about 4.5 MB; making allowance for a certain non-track-density-related noise (e.g. electronics) we conservatively estimate 5-6 MB, i.e. roughly 8% of a central PbPb event.

The maximum estimated TPC gating frequency of 1 KHz would thus result in a front-end data output rate of about 5.5 GB/s, equivalent to the output of 85 Hz worth of central PbPb. From the above considerations this is well compatible with the DDL and HLT bandwidths but can not be written to tape. An HLT facility is thus required to filter out the relevant information contained in each piled-up TPC frame.

1.1.4 Summary of ALICE Running Conditions

Consideration of luminosity, event pileup conditions, maximum TPC gating rate, as well as data rate capability of the TPC front-end electronics including the DDL bandwidth leads to an estimate of maximum event frequencies as far as the TPC is concerned:

1 KHz for minimum bias pp collisions
400 Hz for pileup-free PbPb min. bias collisions
200 Hz for pileup-free PbPb central collisions

The other ALICE subdetectors can run along with these event frequencies, but can not accept significantly higher event rates anyhow - perhaps going up to 1.5 KHz for min. bias and central PbPb collisions in the ITS, TRD and Dimuon detectors, thus capable of defining detector specific level 3 pre-triggers for a pre-scaling that involves the TPC at its lower appropriate rates.

However,

1 KHz pp collisions yield about 5.5 GB/s front-end flow
400 Hz min. bias yield about 15 GB/s front-end flow
200 Hz central PbPb yield about15-20 GB/s front-end flow

from the TPC alone. We shall show below that the intended ALICE physics requires such rates, which we can not write to tape. This consideration makes the case for an intelligent processor front-end system attached to the DAQ, deriving specific triggers and/or reducing the raw event sizes by appropriate filtering procedures: the High Level Trigger (HLT) system. In the following we will first of all consider the task of jet spectroscopy in pp and PbPb. These physics observables will serve to illustrate, both the minimal (pp) and maximal (PbPb) requirements, placed on the HLT functions. A short sketch of other physics observables concludes these considerations.

1.2 Jet Physics in pp and PbPb Collisions

High transverse energy jet production at LHC energy is of interest both from the point of view of higher order QCD (e.g. twist and gluon saturation) [6] and from the program of quantifying jet attenuation in extended partonic matter, i.e. in nuclear collisions at ALICE. The overall goal of the latter idea is to determine the QCD "stopping power" acting on a colour charge traversing a medium of colour charges, in analogy to the Bethe-Bloch physics of QED. This effect will attenuate the energy of the observed jets. Predictions of perturbative QCD as to the mechanism of energetic parton propagation in hot and cold QCD matter address the borderline of present state of the art theory, thus receiving increasing attention. For a length L traversed in QCD matter the induced radiative energy loss is proportional to L^2 and expected to be much higher in a parton plasma than in colder hadronic matter even at moderate plasma temperatures of T≈200 MeV. The effect of "jet quenching" can be estimated [4] to amount to

$$-\Delta E \approx 60\,GeV(\frac{L}{10fm})^2 \approx 30\,GeV for\, L = 7.5fm.$$

Here, L is the transverse radius of the PbPb "fire-sausage", which is the relevant geometrical length scale as we are observing jets with average center of mass angle of 90^0 with the ALICE TPC positioned at $\mid \eta_{CM} \mid < 1$. Thus the main task is to measure the inclusive jet production yield at mid-rapidity as a function of E_T both in pp and central PbPb. Of course one is, more specifically, interested in the details of the jet fragmentation function [1]. The capability of ALICE to reconstruct in detail the jet fragmentation function in the charged track sector is crucially important in view of ongoing theoretical study concerning the detailed consequences of primordial partonic mechanisms of energy loss. It turns out that the hadronization outcome, from the energy loss components of the leading jet parton, may also be partially contained within the typical jet emission cone, resulting in an increase of local E_T emission but expressed by relatively softer hadrons.

The picture of quantifying energy loss of the primordial jet may thus be an over-simplification. One may have to investigate, instead, the microscopic changes, at track-by-track level, occuring within the fragmentation cone of a high E_T jet created in PbPb collisions, in order to appropriately capture the overall attenuation effect acting on a leading parton traversing high energy density partonic matter sections of the interaction "fireball". In this view, the jet attenuation phenomena should reside in a characteristic softening of the jet cone fragmentation function, rather than in a simple jet energy loss scenario, as considered above. The microscopic tracking approach of ALICE may thus prove advantageous, in comparison to the summative E_T inspection by calorimeters.

1.2.1 HLT Function in PP for Low Cross Section Signals

As stated above, we probably will get only $\sqrt{s} = 14$ TeV initially for the pp beam. For low cross sections signals such as jets, Ω and Υ we need about 10^{10} events, in order to record

$5 \cdot 10^4$ jets with $E_T \geq 100$ GeV
10^5 Ω in acceptance
10^3 $\Upsilon \rightarrow e^+e^-$ in acceptance.

The ideal solution would be to reduce the luminosity further (below $2 \cdot 10^{30}$), which technically is very difficult. Assuming a luminosity of 10^{29} would result in an average of 1.7 min. bias events per TPC frame at 7 kHz event rate. For that scenario an average TPC event content of ≈ 0.5 MB at a maximum trigger rate of 1000 Hz will lead to 0.5 GB/s to DAQ. This is a writing speed compatible with "first year" DAQ without employing an HLT.

If LHC can not go lower than a luminosity of $2 \cdot 10^{30}$ at ALICE for technical reasons, we need to employ HLT functionality. Now the average number of events per TPC frame is about 25 partially half events pile-up and thus the average TPC event content is roughly 5 MB. Therefore at 100 Hz DAQ saturation occurs assuming a first year 0.5 GB/s bandwidth and we would get only 10^9 events per year (i.e. 5 months), which is unsatisfactory.

Employing HLT for event filtering at full TPC frequency of 1000 Hz to filter out the trigger event only, we expect at least a 10:1 reduction of raw data flux. Therefore at the same DAQ bandwidth of 0.5 GB/s to tape we could store 10 times the amount of events thus exhausting the maximal TPC gating frequency. In that scenario HLT-processors for about 250.000 tracks/s are required. Derived DAQ bandwidth and data storage needs are

0.5 GB/s to tape from TPC alone for the first year.
0.7 GB/s to tape from TPC, TRD and ITS together.

That leeds to a total storage of 5 Petabyte per year pp, which is very high, but not done every year.

In the following section we shall demonstrate that the typical one-year data output of ALICE for PbPb running 2007 and beyond will fall in the vicinity of 1.8 Petabyte "only". However, due to the relatively short expected Pb beam periods of LHC, the DAQ bandwidth has to increase from about 0.5 GB/s in first year to about 1-1.2 GB/s after 2007, in spite of increasing HLT effort.

1.2.2 Jet Physics in PbPb Collisions with HLT Trigger

The physics questions to be persued first are: How does the inclusive jet cross section at or near 90^0 vary with the total transverse energy E_T? And what are the properties of the fragmentation function? Both to be compared to elementary data from pp.

Recall M. Mangano's estimate [6] of one jet with $E_T \geq 100$ GeV in $2 \cdot 10^5$ events for the reduced TPC acceptance of $\mid \eta \mid < 0.5$ at $\sqrt{s}$=14 TeV min. bias pp collisions. How to scale to central PbPb collisions at $\sqrt{s}$=5.5 TeV? Employ QCD scaling to extrapolate the jet cross section from 630 and 1800 GeV $\sqrt{s}$ as reported by D0 and CDF [1]. As to the dependence of jet multiplicity on target/projectile participant nucleon pair number in AA the QCD expectation is $A^{4/3}$ where A≈185 in a "central" PbPb collision. Note the extra factor of 1/3 in the exponent over "wounded nucleon" models that scale with A. Thus the jet multiplicity for standard physics would increase by $A^{4/3}$ but decrease by about 10 due to energy scaling down from $\sqrt{s}$= 14 TeV (Mangano estimate) to $\sqrt{s}$=5.5 TeV. This leaves a gain factor of about 100 from pp at $\sqrt{s}$=14 TeV to AA at $\sqrt{s}$=5.5 TeV. The interesting first order effect of "jet attenuation" degrades the jet energy by the radiative loss of $-\Delta E_T$. Baier et al. [4] estimate this to be -30 GeV at $\Theta \approx 90^0$ in PbPb (see the previous section). This shift, if independent of E_T, would reduce the jet multiplicity by a factor of about four, for the case of 130 GeV jets shifted down to an observed 100 GeV in central PbPb. This reduces the expected overall scaling factor from pp to PbPb to a final value of 25, on which we will base the considerations below:

The jet multiplicity per central PbPb at $\sqrt{s}$ =5.5 TeV equals that of 25 min. bias pp collisions at $\sqrt{s}$=14 TeV.
This results in one $E_T \geq 100$ GeV jet every about 9000 central PbPb, in the effective TPC acceptance (for full jet containment) of $|\eta| < 1/2$.

Note that we are focusing here on jets at and above 100 GeV in order to stay compatible with the assumption that jets can be identified by relatively simple on-line tracking algorithms. At $E_T \geq 100$ GeV jets have on average a unique charged track topology and a sufficient charged track multiplicity of $< n_{ch} > \approx 10$, to stand out over the fluctuating mini-jet background even in central PbPb collisions.

Jets at $100 \leq E_T \leq 200$ GeV in central PbPb, $\sqrt{s} = 5.5$ TeV

We assume again E_T attenuation by perhaps up to 30 GeV. There are around 10 charged particles in the jet. The "leading particles" of a 100 GeV jet are in the $20 < E_T < 30$ GeV domain, which is compatible with TPC E_T tracking resolution.

In such a scenario we need more than about 10^8 inspected events in the TPC: this will give $\geq 10^4$ events with $E_T \geq 100$ GeV even at 30 GeV energy attenuation.

One PbPb year corresponds to 10^6 s or 2 $\cdot 10^6$ s run time with an inspection rate of 200 Hz in TPC, which we can not write to tape for obvious reason. But employing an HLT based on on-line jet-finder tracking algorithms would result in 200 Hz central PbPb TPC inspection by the HLT, which yields $\geq$ 50 jets per hour with attenuation. The resulting maximum HLT duty is to reconstruct up to 2 $\cdot 10^6$ tracks/s.

We will sketch below an HLT TPC-tracking-based jet finder algorithm that could serve as a jet-trigger for $E_T \geq$100 GeV jets, capable of a 200 Hz central PbPb collision rate. Before dealing in more detail with HLT jet triggering we sketch other ALICE HLT tasks. However, let us conclude here that both the minimum demands (pile-up in pp) and the maximum demands (jets in PbPb) on the HLT functionality have been involved above for jet spectroscopy. All further observables will stay well within this HLT budget.

1.3 Bottonium Spectroscopy

We consider bottonium spectroscopy and chose as a key example the decay of Υ (9460) $\rightarrow e^+e^-$, which creates two electron tracks of about 5 GeV. The TRD is constructed to increase electron selectivity over pions of equal momentum. The HLT-trigger is thus built on TRD precognition of an e^+e^- pair (with roughly correct invariant mass). This pre-trigger hands down two ”regions of interest” (ROI) to the TPC, thus involving inspection of two TPC-sectors for more accurate verification and momentum plus specific ionization measurement of the two tracks, leading to fast rejection or invariant mass verification on-line. The latter activity carried out by the TPC HLT processors leads to an Υ candidate trigger. The Υ cross section is as low as the jet physics cross section considered for ALICE thus far. We estimate one $\Upsilon \rightarrow e^+e^-$ decay in the TPC/TRD acceptance in about 10^4 central PbPb collisions (including electron pair efficiency in the TRD and dead areas). This estimate is based on a full coverage of the TPC by the TRD. Full TRD coverage represents a future ALICE upgrade potential. With about 60% coverage in initial ALICE running, it thus follows that about 10^8 PbPb collisions are required to accomplish a satisfactory Υ spectroscopy. Without HLT functions the maximum yearly ALICE event statistics would amount to about 10^7 events only.

In order to discuss ways of proceeding to higher event frequencies than 10-20 Hz it is important first to note the technical constraints: the TRD, by itself, could perhaps trigger at 500 Hz, but if we insist that any Υ candidate event preselected by the TRD meets with a concurrent pile-up free TPC event, we have to cut down to 200 Hz for central PbPb and to 400 Hz for min. bias PbPb due to the TPC limitations. Both running modes will yield about the same number of Υ decays per unit time. Let us, therefore, concentrate on central collisions. At a common HLT on-line inspection rate of 200 Hz for central PbPb in the TRD and TPC we can inspect $4 \cdot 10^8$ events per ALICE year of about $2 \cdot 10^6$ effective running seconds. It remains to be shown that combined TRD-TPC HLT on-line tracking can reduce the selected data flux down to a level that can be recorded without exceeding the DAQ bandwidth. With full TRD coverage this promises to cover about $2 \cdot 10^4$ Υ decays per year, just sufficient for detailed spectroscopy of the Υ family.

1.4 HLT Event Filter for Open Charm Study

The physics goal of open charm cross section analysis (by D-meson decay topology/secondary vertex) up to now defines the official ALICE goals concerning the DAQ bandwidth, taping rate and stored data size: 10 Hz of central PbPb for $2 \cdot 10^6$ seconds amounting to $2 \cdot 10^7$ events. If written to tape we have a bandwidth of 660 MB/s for the TPC alone and acquire a total of 1.3 Petabytes. Could we get this physics at lower media cost?

The idea is to track the central PbPb events completely at 200 Hz, on-line with the HLT processors. Having the track information we exclude the low p_T tracks, which do not contribute to the hadrons emitted at the D decay vertex. With $< p_T >$ of the D assumed to be 1 GeV/c, the relevant K$\pi\pi$ (for charged D) and Kπ (for D^0) channels result in tracks above 0.8 GeV/c. If we assume the $< p_T >$ of pions to be 0.6 GeV/c the fraction of tracks with $p_T >$ 0.8 GeV/c is about 0.25% of the total. As the secondary D decay vertex is very close to the main vertex one could also remove large impact parameter non-vertex and ghost tracks. The procedure would be to define a ”pipe” of raw data along each vertex track at p_T >0.8 GeV, which will then be read out. That procedure needs a further careful simulation. It promises an event filtering of about 1/10. Within the maximal HLT goal, defined by high E_T jet spectroscopy, that physics represents an HLT activity easily carried out cooperatively and concurrent to the major task of tracking 200 PbPb events per second.

1.5 Summary of HLT, DAQ and Storage Requirements

In summary we expect to cover with sufficient statistics per ALICE running year the observables jet production, and bottonium and open charm yields, by means of a balanced effort in HLT and DAQ bandwidths.

1. HLT is used minimally in first year pp at $L=2 \cdot 10^{30}$. We need in principle "only" a vertex-finder algorithm, but the events (containing 25 superimposed displaced sub-events) have to be completely cluster-analyzed. At 1000 Hz TPC rate clustering throughput is about 5.5 GB/s of raw data, but tracking needs are minimal. Maximum HLT use occurs in the trigger on jets in central PbPb at 200 Hz TPC. The clustering and tracking effort rises to up to 20 GB/s.
2. The DAQ bandwidth is intermediate in first year pp minimum bias runs at 1000 Hz. If the ideal low luminosity of $L=10^{29}$ can be technically realized, we need no HLT and get about 0.5 ±0.1 GB/s to DAQ from the TPC. All the other detectors (unless dimuon adds new tasks) will add 0.1 to 0.2 GB/s. Total DAQ 0.65 ±0.1 GB/s. For higher luminosities we require HLT selection of the relevant TPC event, thus staying within the same DAQ budget.

   The DAQ bandwidth is maximal for "first year PbPb" writing 10-20 Hz of central PbPb to tape without any HLT action: Total DAQ 0.9 ± 0.2 GB/s. Further "trigger mixes" will perhaps increase that budget to 1.2 GB/s. The other anticipated trigger modes of later years will stay at or below the DAQ bandwidth upon proper trigger mixes under HLT trigger/filter procedures approaching 200 Hz TPC inspection rate.
3. The storage format is maximal in first year pp because we shall gather 10^{10} min. bias events in 4-5 months at 1000 Hz under HLT,

which results in about 6.5 Petabytes. Lateron, PbPb for $2 \cdot 10^6$ seconds per year at a total ALICE rate of 1.2 GB/s will give 2.4 Petabytes.

1.6 A Further Mode: Data Compression (only) in HLT

As a remaining option of front end intelligence employment for TPC data volume reduction let us consider to simply do cluster-finding online and then write to tape without any tracking, trigger specific search algorithms (vertex, jet, back-to back e^+e^- pair) or invariant mass determinations. Which degree of data compression can be achieved? Before making estimates we propose, as a general remark, that in a traditional off-line analysis (like in NA49 or STAR) one seldom finds reason to return to the raw data once the analysis chain is set up correctly. However the cluster level is often returned to . Thus clustered data are almost equivalent to raw data. The real optimizations, e.g. for specific ionization, occur at the step from cluster to track.

At the STAR L3 prototype the on-line cluster finder achieves a sixfold data compression (after zero suppression), which with about 200.000 clusters per central Au+Au collision leads to a 2 MB total event size. Thus we saw in STAR that one cluster requires on average 10 bytes of output. No attempt was made as of yet to bring down this single cluster format, but there must be considerable reserve in the 10 bytes. Consider now the present HLT proposal to replace conventional cluster-finding (in a memory) by ”in-flight” tracklet determination in FPGA based circuits. This way n successive clusters are tied up in a tracklet, say $< n > = 7$. It is clear that specification of the tracklet on average will not require 70 bytes. We might expect that 20 bytes suffice, which would result in an overall compactification factor of about 15 (and yet could use a re-fitter at the tracklet level or unfolding etc.) by clustering only. This HLT option would cope with about 150 Hz central PbPb yet staying compatible with the DAQ bandwidth and could be an HLT option for later years of ALICE operation. After two years of off-line operation with the full raw TPC data output, the RHIC STAR collaboration now converts to record HLT clusters from its TPC only.

1.7 Conclusions Concerning Demands on HLT

From the considerations in all of the above sections it follows that the maximal envisioned ALICE HLT task will consist in complete on-line cluster finding and tracking of TPC events, as motivated by high E_t jet and open charm or bottonium spectroscopy, at 200 Hz central PbPb as recorded in the TPC. In all the above cases the by far major computational effort will be devoted to a complete reconstruction of the event on-line, albeit with a characteristic lower precision in detail, in comparison to the ensuing off-line analysis, devoted to the triggered events. In comparison to the clustering-tracking effort the derivation of on-line trigger signals, corresponding to specific physics observables, will require a relatively modest additional computational effort. The latter computational economy follows from on-line data handling economy. The track data output does not get stored, then to be reread as in off-line analysis (highly CPU time consuming) but is immediately handed, track by track, from the tracking to the trigger evaluating algorithms.

In ending these qualitative considerations concerning the proposed ALICE HLT system let us add a quantitative estimate of the required HLT CPU power, as based on our experience with the L3 prototype system explored in the STAR experiment at RHIC, BNL. It is attached there to the TPC subdetector. This TPC has about one-third of the ADC channels of the ALICE TPC. Furthermore, we may conservatively estimate that the charged particle multiplicity should increase, from RHIC $\sqrt{s}$=200 GeV to ALICE $\sqrt{s}$=5.5 TeV, by a factor of about four. As both TPCs have the same acceptance we thus expect an ALICE TPC data format of about 12 times the STAR format. The prototype STAR HLT system (called L3 there, see [7] was shown in the year 2001 RHIC running period to cope with the rate of 40 Hz for central AuAu collisions. For the ALICE HLT we require a 200 Hz rate: a further factor of 5, bringing the total ALICE computation effort up from the STAR prototype by a factor of about 60. In STAR 52 PCs of 1997 vintage were employed in the L3 system (mostly $\sim$ 600 MHz). Adopting expectation from "Moore' law", in extrapolating to ALICE HLT standard PCs of vintage 2005 we conservatively expect an overall CPU/network/IO speed increase of about three. This simple extrapolation results in the expectation that the ALICE HLT functionality, as envisioned in the previous sections, will require about 1000 processors. Of course the scaling assumed here is not trivial and will require advanced methods concerning networking and computation methods to be outlined in later sections of the present document.

2 HLT Trigger for Jets at $E_T \geq 100$ GeV in PbPb

In this section we describe the application of a cone jet finder algorithm to derive an on-line HLT jet trigger from TPC inspection of central PbPb collisions at 200 Hz rate. It is our purpose to test the jet detection efficiency, the degree of suppression of accidental background looking like jets, and the specific demand on CPU time placed by the trigger algorithms over and above the computing budget already expended in the preceding clustering-tracking stages.

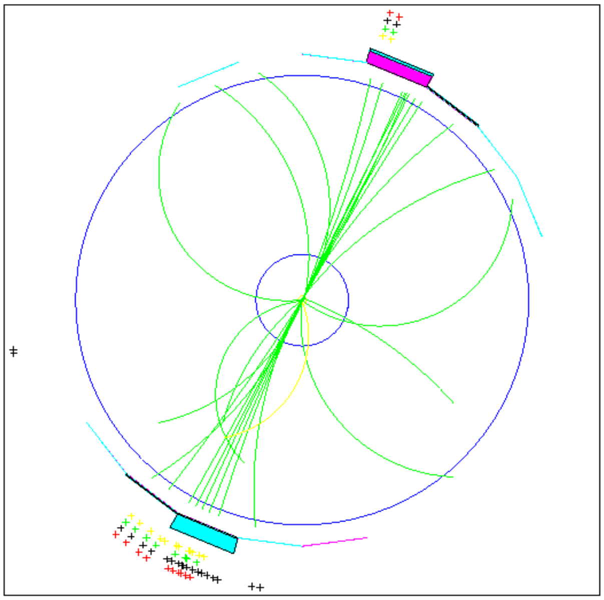

Figure 1: A typical di-jet tracking event with E_T of 300 GeV observed by CDF in Tevatron $p\overline{p}$ collisions [1].

The present study is restricted to 100 GeV inclusive jets (without consideration, at first, of its near back-to-back partner). In principle the domain of jet total transverse energies that may be analyzed with ALICE charged particle tracking at 200 Hz PbPb event rate ranges from 100 GeV (where the statistics is good in one ALICE run year of about 10^6 sec) up to about 200 GeV where the jet statistics has dropped by a factor of about 15 and is, thus, marginal. The focus at $E_T \geq 100$ GeV represents a qualitative consideration of the following conditions:

- The fluctuation in the ratio of charged particle to total jet energy diminishes with increasing jet charged particle multiplicity (which is about 10 at 100 GeV).
- The jet signal should be topologically distinct also in the high track density of a central PbPb collision, i.e. have a "high" charged track multiplicity to avoid observational bias.
- The leading jet particle energy should not exceed the limits of accurate enough p_T measurement in the ITS-TPC-TRD complex, i.e. $p_T \leq 50$ GeV/c.
- On the other hand most of the total E_T should be in particles with $p_T \geq 2$ GeV/c.

In Fig. 2 we illustrate a typical di-jet tracking event with E_T of 300 GeV observed by CDF in Tevatron $p\overline{p}$ collisions [1]. The jet related topological features dominate, by far, the non-jet related track background. This will be similar in pp at ALICE. However, note that the jet cone algorithm [5] employed in $p\overline{p}$ is aiming at an exhaustive coverage of the jet track manifold, down to tracks at rather large angle relative to the jet axis (to reconstruct the full fragmentation function). One thus normally employs a jet cone radius of $R = 0.7$ in the plane of pseudorapidity η vs. azimuthal angle ϕ (ranging from zero to 2 π). In ALICE this would comprise almost the full rapidity acceptance, and 22% of the azimuthal range. This may be appropriate for ALICE pp jet study but is clearly not useful in a straight forward manner under LHC PbPb conditions, because every such cone near mid-rapidity would now contain charged tracks with a total of about 0.7 TeV transverse energy, with a fluctuation RMS of about 40 GeV. This follows from a HIJING simulation assuming a midrapidity charged particle density of 6000. As the average charged track total E_T of a 100 GeV jet is 60 GeV [1], the

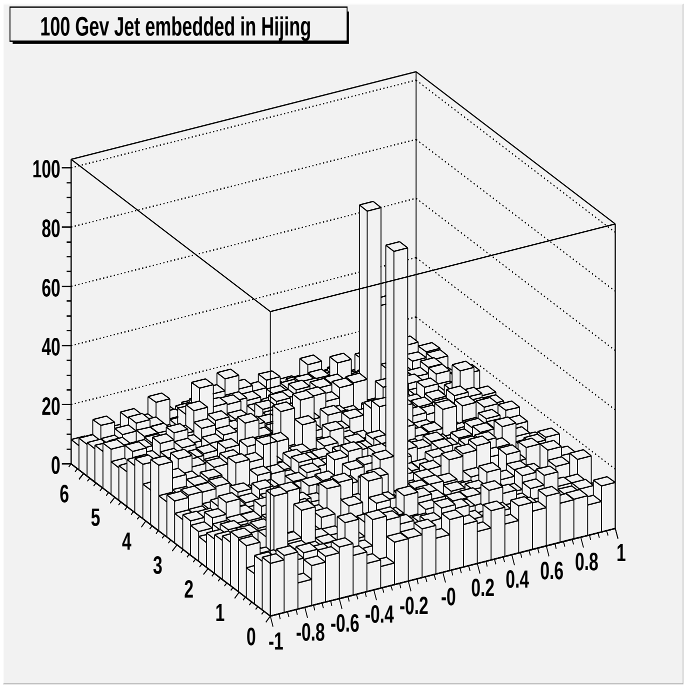

Figure 2: Typical 100 GeV Di-jet event with granularity $\Delta\eta = 0.1$ and $\Delta\phi = 0.25$.

jets can not be well disentangled. Let us emphasize, again, that the HLT task considered here is only to find the jet candidate events. This requires a narrow jet cone finder algorithm - to exploit the overall typological jet pattern. Off-line analysis will subsequently study the jet activities in any cone required.

We wish to stay with the cone algorithm for its relative computational efficiency (required, at least, in the on-line analysis) but consider a significant reduction of R, to 0.3 or 0.2, for the process of on-line trigger generation, which is **merely jet finding**. The triggered events will then be written to storage in full raw data format, for off-line jet analysis of any kind. The jet finding conditions are illustrated in Fig. 2. Here and in the following, we use the code Pythia version 6.161 to generate elementary pp events with a contained hard parton scattering creating scattered partons of 100 GeV transverse momentum. These elementary events are then analyzed with the standard cone algorithm (with $R = 0.7$) to identify the highest energy jet in the event, representing the outcome of the initial parton scattering. The charged tracks found within the cone of this particular jet are then imbedded into a central PbPb HIJING event, represented by the charged track distribution in η and ϕ. Actually it turns out that the HIJING average track and energy density is flat within the entire ALICE TPC acceptance of $\mid \eta_{CM} \mid \leq 1$. Fig 2 thus represents the image of a typical 100 GeV di-jet event in a Lego plot with granularity $\Delta\eta = 0.1$ and $\Delta\phi = 0.25$. The distribution and fluctuation of charged track transverse energy, observed here, would be typical of calorimetric summative E_T analysis. In this picture the typical jet correlation of high E_T tracks, closely packed in a narrow cone about the jet axis, creates a topologically distinct pattern that stands out well above the background.

In ALICE we have to base recognition of the topological jet signature on an appropriate analysis of jet cone correlation among high E_T individual charged particle tracks. For $p\overline{p}$ collisions at the Tevatron the CDF Collaboration has recently published a comprehensive study of jet physics, based on charged particle tracking only [2]. They study the systematic evolution of jet fragmentation functions upon variation of cone jet-finder algorithm, downwards from R=0.7 to 0.2 and note, in particular, that at R=0.2 still 80% of the total charged particle E_T is contained in the jet cone. This finding encourages us to work with cone radii of 0.3 and 0.2, respectively, for on-line jet finding to result in a fast trigger, in PbPb central collisions where higher cone radii would meet with increasing background fluctuations.

Within an on-line HLT clustering-tracking procedure for the entire event each track emerges with a determined center of mass momentum vector. For CPU economy of the ensuing jet finder algorithm it is essential to select the relevant track candidates right then, rather than depositing all tracks in a register that the cone finder would have to reread. We thus base the jet finder on a cone correlation of high p_T tracks which are handed, above a certain p_T cutoff, directly from tracking to the jet finder algorithm. Within the latter we then inspect the event in terms of requiring n charged tracks above a p_T or E_T cutoff of m GeV, contained within a cone of radius R=0.2 or 0.3 in η and ϕ.

In the simulation with elementary Pythia jet identified events of 100

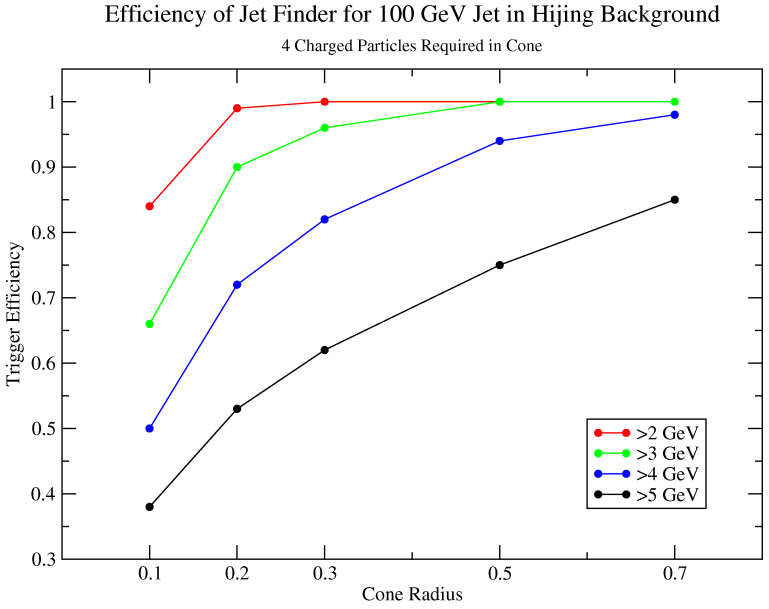

Figure 3: Efficiency of cone jet finder trigger applied for different cone radii and threshold. At least 4 charged particles over threshold are required to be inside the cone.

GeV initial partonic transverse energy/momentum, imbedded into HIJING simulated events for central PbPb collisions, at ALICE energy and within the ALICE acceptance, we have studied the jet-detection efficiency and accidental background rate of various trigger-defining options, employed in the cone jet-finder algorithm. As an example Fig. 3 shows the resulting jet recognition efficiency requiring at least four charged tracks correlated within jet cone radii ranging from 0.1 to 0.7, for various track p_T cuts ranging from above 2 GeV/c to above 5 GeV/c. Fig. 4 illustrates the background trigger rate of these cone trigger options, in terms of accidental background being created by random p_T, ϕ fluctuations in average HIJING central PbPb simulated events. The finite ALICE transversal momentum resolution should not lead to significant changes.

At the level of this preliminary study an optimum of trigger efficiency

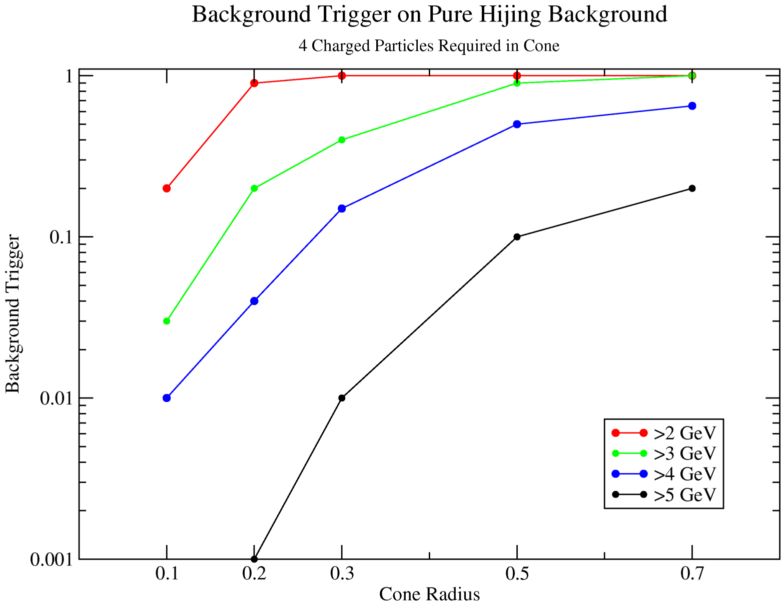

Figure 4: Background trigger rate of cone jet finder trigger measured on pure Hijing background events. Parameters are the same as in Fig. 3.

vs. accidental trigger background rate may be accomplished in requiring 4 charged tracks above 4 GeV transverse momentum within a jet cone of R=0.2. The resulting jet efficiency, of about 0.72, coincides with a background trigger rate of about 4 %. I.e. this trigger mode, as applied in HLT central PbPb collisions inspection at 200 Hz, created a jet candidate trigger rate of about 8 events per second that can easily be written to tape, for comprehensive off-line analysis. Furthermore, the events collected under this HLT trigger mode can be considered as almost bias free concerning any other physics observable of interest: more than 99% of the resulting HLT triggers are based on random event-by-event fluctuations in the high p_T sector, immaterial to many other ALICE physics observables.

We thus argue that an appropriate on-line HLT jet trigger based on charged track 3-momentum determination on-line, at the tracking stage, and on an optimized cone-type jet-finder algorithm, will offer the required jet recognition efficiency, within a selectivity above background that will reduce the 200 Hz rate of HLT inspected central PbPb TPC events, down to a candidate trigger rate of about 8 Hz (essentially bias free as concerns analysis of any other observables, except for high E$_T$ jets). This latter event rate fits well within the overall anticipated ALICE TPC to DAQ bandwidth, of 10-20 events per second. Thus it will be possible to record other trigger modes concurrently.

It remains to be shown that the HLT jet-cone trigger search algorithm, as implied in this section, does not inflict a significant additional budget concerning CPU time, in addition to the -already maximal- HLT task, to perform cluster and track analysis for central PbPb TPC events at 200 Hz rate. At present we estimate the jet cone algorithm to require less than one second in the mode illustrated above. Both this estimate, and also the accidental background should improve with a further, more comprehensive optimization of the detailed trigger conditions.

A higher jet recognition efficiency might actually result from exploiting the approximate back-to-back topology of dijet production (this trigger mode could also be more interesting, physics-wise!). One could thus search with a double cone algorithm, relaxing the charged high p$_T$ track number requirement in each cone from the above 4-5 down to 2-3. In a single cone this leads to jet recognition with up to 90% efficiency but creates too high a background accidental rate. The additional topological constraint implied by di-jet events should significantly reduce the background rate, yet leaving one with an overall dijet efficiency of about 80%.

In summary we expect, from the present level of jet physics simulation, to be able to present an optimized HLT cone jet finder trigger for inclusive jets of $E_T \geq 100$ GeV that delivers 75-80 % efficiency with a background trigger rate of 1-2 %. The expected CPU time budget is below 20% of the effort required for cluster finding and tracking.

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