PROCEEDINGS OF SCIENCE

ALICE

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For the ALICE Collaboration

The ALICE detector has been commissioned and is ready for taking data at the Large Hadron Collider. The first proton-proton collisions are expected in 2009, while nuclear beams are expected for 2010. In this paper, the ALICE experiment and its specificities in comparison with the other LHC experiments are shortly described, and the main goals of the first pp and PbPb runs discussed. The status of the detector will be reviewed and results from the 2008 and 2009 runs with cosmic rays and injected beams are discussed.

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[1] Speaker

1.The ALICE experiment

ALICE is the only experiment at the LHC dedicated to the study of Heavy Ion Collisions. Contrary to RHIC, where four detectors have been constructed and could therefore focus on different measurements, ALICE had to be designed to cover most of the relevant observables at the same time. Moreover, during the years of its design and construction, ALICE has considerably evolved and expanded its physics reach, including several additional small detectors and three major ones, for which formal addenda to the Technical Proposal were approved: the Muon Spectrometer in 1996, the Transition Radiation Detector in 1999 and the Electromagnetic Calorimeter in 2006.

ALICE has a very different optimization compared to the other LHC experiments. First of all, the prime concern in the design of the experiment was the need for robust tracking, able to handle the very large number of tracks which characterize Heavy Ion Collisions. Moreover, for the understanding of nuclear collisions it is essential that as many of the produced particle as possible are measured and identified, for the widest possible range of transverse momenta (typically from 0.1 to 100 GeV/*c*) and for all particle types: electrons, muons, photons and hadrons. The recent results from the Relativistic Heavy Ion Collider [1,2], such as the mass and quark content ordering of the v_2 flow coefficient for hadrons or the different suppression patterns for high transverse momentum pions and photons, have confirmed the essential role of particle identification for the interpretation of the results. To handle the high particle multiplicity, ALICE has been equipped with very high granularity tracking detectors providing 3-Dimensional space points (several hundred millions of points) and operating in a moderate magnetic field. The electromagnetic calorimeters have been placed at very large distance from the interaction points (the Crystal Photon Spectrometer is placed at 4.6 m, to be compared with typical values of 1 to 2 meters in other collider experiments). The coverage for low-p_t particles has been achieved by keeping the detectors extremely thin, in addition to using a moderate field. In fact, the precision silicon detector layers of the ALICE Inner Tracking System are just about 1% of a radiation length (X_0) each, and particles in ALICE traverse in total less than 10% of an X_0 to reach a radius of 2.5 m. To achieve good resolution also for large momenta, the low magnetic field has been compensated by the very long track length measured, reaching a bending power (BL^2) value similar to the one of the CMS tracking system. Finally, to identify leptons, photons and hadrons, including short-lived particles, such as hyperons, D and B mesons, ALICE features essentially all known techniques: dE/dx, Cherenkov & Transition radiation detectors, Time Of Flight, calorimeters, muon filter and topology (secondary vertices, kinks). All these features, of course, come at a price: fairly slow detectors, matched to the low luminosity of nuclear beams in the LHC, and limited acceptance. On the other hand, due to the lower luminosity, the ALICE environment will not be as hostile as that of the other LHC experiments from the point of view of radiation, allowing the use of technologies of moderate radiation resistance.

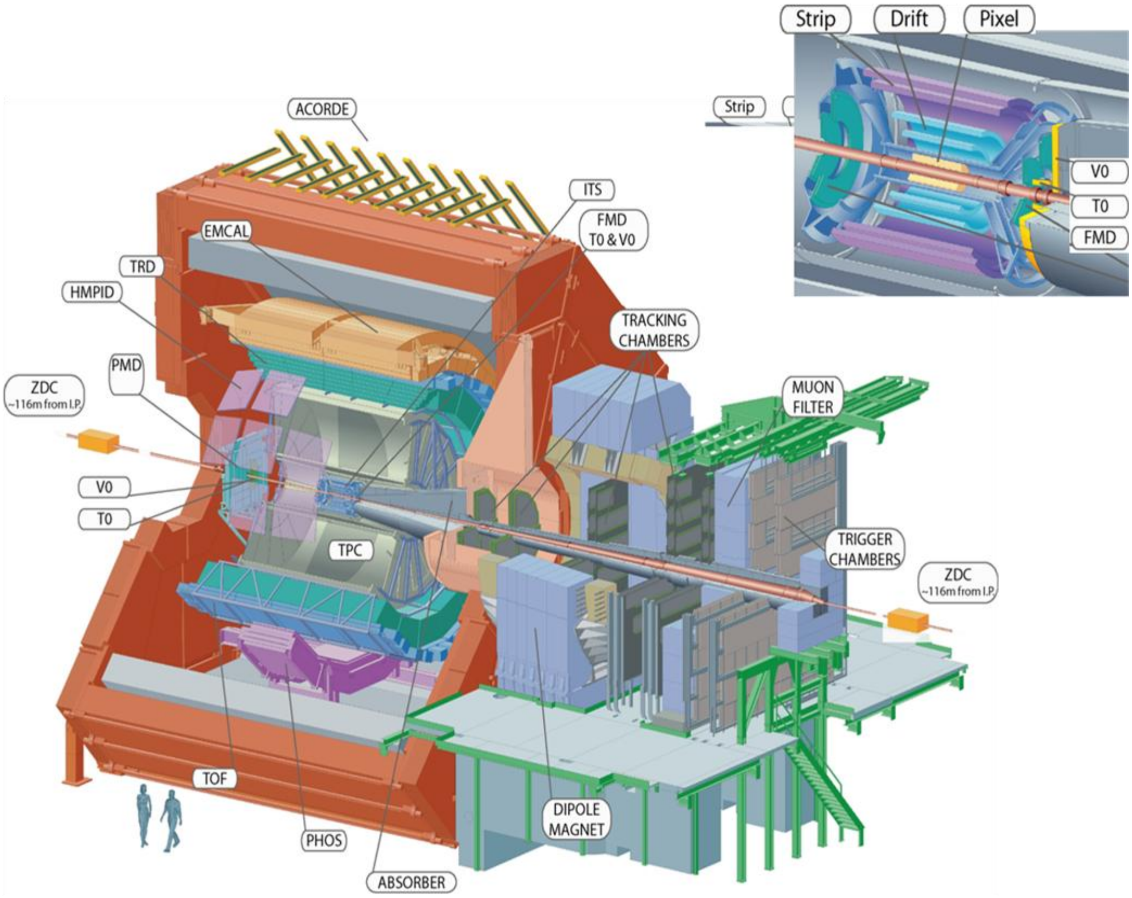

Figure 1: Overview of the ALICE detector

The final ALICE detector configuration[3], shown in figure 1, consists of a central detector system, covering about two units of rapidity, embedded in a very large solenoid with a field of 0.5T, a one-arm forward muon spectrometer and forward multiplicity and centrality detectors. From the inside out, the barrel contains an Inner Tracking System (ITS) of six layers of high-resolution silicon pixel (SPD), drift (SDD), and strip (SSD) detectors, a cylindrical Time-Projection Chamber (TPC), three particle identification arrays of Time-of-Flight (TOF), Ring Imaging Cherenkov (HMPID) and Transition Radiation (TRD) detectors, and two electromagnetic calorimeters (PHOS and EMCal). All detectors except HMPID, PHOS, and EMCal cover the full azimuth. The TPC and the ITS contribute to the particle identification via the measurement of specific energy loss. An array of scintillators (ACORDE) on top of the L3 magnet is used to trigger on cosmic rays.

In figure 2 (left panel) the momentum coverage of the various ALICE PID detectors is shown, demonstrating the extent of the coverage achieved. In addition, short-lived particles are identified through their decay topologies: in the right panel of figure 2 the impact parameter resolution expected in ALICE is shown, which is adequate for the measurement of D and B meson decays. K and Λ decays can be efficiently reconstructed for transverse momenta up to more than 10 GeV/*c*. The very fine granularity of the tracking detectors, providing a large number of space points per track, provides high efficiency tracking for charged particles even at the highest particle multiplicities foreseen at the LHC with Pb beams, with a lower limit in momentum lower than 200 MeV/*c*. The very long track length measured allows ALICE to achieve an excellent momentum resolution ($\delta p/p < 5\%$ at 100 GeV/*c*). Several smaller detectors (ZDC, PMD, FMD, T0 and V0) used for global event characterization and triggering are located at small angles. The combination of the central and forward detectors provides coverage for the measurement of charged multiplicity which extends from -3.4 to +5 in pseudorapidity. An Electromagnetic Calorimeter, EMCal, covers about a third of the azimuth and provides improved energy resolution and triggering for jets. A high-resolution crystal photon spectrometer, PHOS, is placed at a very large radial distance from the interaction point (4.6 m). The muon spectrometer covers the forward rapidities, between -2.5 and -4, and features a complex arrangement of absorbers, starting very close to the interaction point (90cm) to minimize muon background from weak hadronic decays, and fourteen planes of tracking and triggering chambers, using 2-D pad readout to handle the high multiplicities.

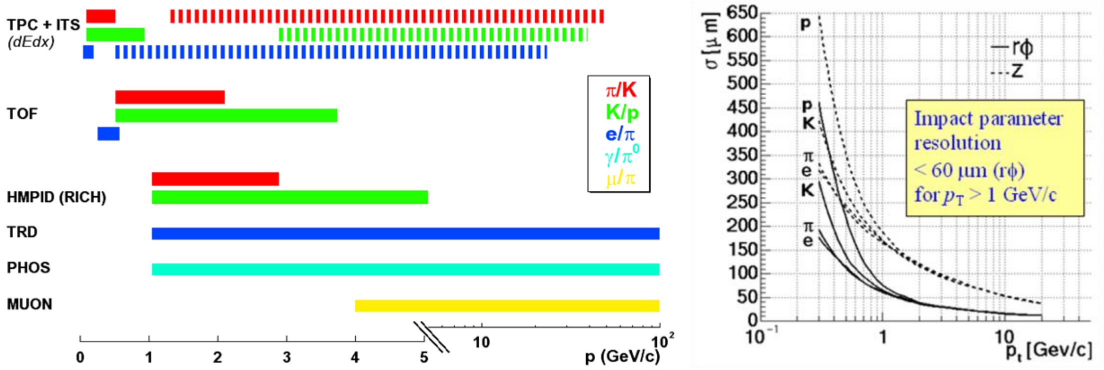

Figure 2: Left: particle identification in ALICE: momentum range and detectors used. Topological identification, not included in this plot, can reach over 10 GeV/*c* for K and Λ. Right: ALICE impact parameter resolution as a function of transverse momentum.

The hardware trigger in ALICE combines the input from detectors with fast trigger capability (T0, V0, ZDC, SPD, TOF, PHOS, EMCal, Muons, ACORDE). It operates at several levels (pretrigger, L0, L1 and L2) to satisfy the individual timing requirements of the different detectors, as the ALICE electronics is in general not pipelined. In addition, a software based High-Level Trigger (HLT) using a farm of up to 1000 multiprocessor PCs will perform essentially complete event reconstruction for a detailed on-line analysis. It allows event selection, but also data quality monitoring or event size reduction via compression or selection of a fraction of the data to be read out (region of interest).

2. Status of the ALICE detector and commissioning results

When ALICE interrupted the installation activities in July 2008, in order to be ready for stable conditions for the start of beams in the LHC, most of the detector elements, namely ITS, TPC, TOF, HMPID, V0, T0, FMD, ACORDE, the entire MUON Spectrometer and the Detector Control System (DCS), were ready and commissioned. Both the Data Acquisition (DAQ) and the High Level Trigger (HLT), although fully operational, were only partially deployed since no Heavy-Ion running was expected (about one quarter of the final capacity). One fifth of the PHOS and of the PMD and one quarter of the TRD, which is a more recent addition to the ALICE setup, were also installed, while the installation of recently approved EMCAL was not yet started.

At that moment two periods of continuous data taking with cosmic rays had already taken place. A first run of 12 days in December 2007 was mainly used to debug the global and detector specific data taking systems. The second one, of five weeks (February-March 2008), was used to verify that all systems could efficiently operate without mutual interference. A third, much longer run, spanned the period from May 2008 to the foreseen start-up of the LHC in October. In the 515 days of data taking a total of about 3 PB of data was read-out of which 350 TB was recorded to tape. This massive effort allowed a thorough tuning of all data taking aspects and substantial progress in the understanding of the detectors. In particular, the calibration and alignment procedures were commissioned, and for several detectors the data quantity and quality was sufficient to actually perform the calibration and alignment.

During the cosmic runs ALICE was triggered with the silicon pixel multiplicity trigger tuned to select single muons traversing the pixel layers, and therefore the ITS and the TPC, or with the ACORDE dedicated cosmic trigger array. Later, thanks to the very low noise levels attained, also the TOF array was used to trigger on cosmic rays, allowing the selection of muons crossing, e.g., specific TRD modules. In addition, a number of calibration runs were taken with specific triggers, e.g. to monitor the drift speed stability of the Silicon Drift Detectors using the integrated MOS charge injectors, monitoring the TPC drift speed using laser-generated tracks or calibrating the TPC gain using the signals from Krypton injected in the drift volume.

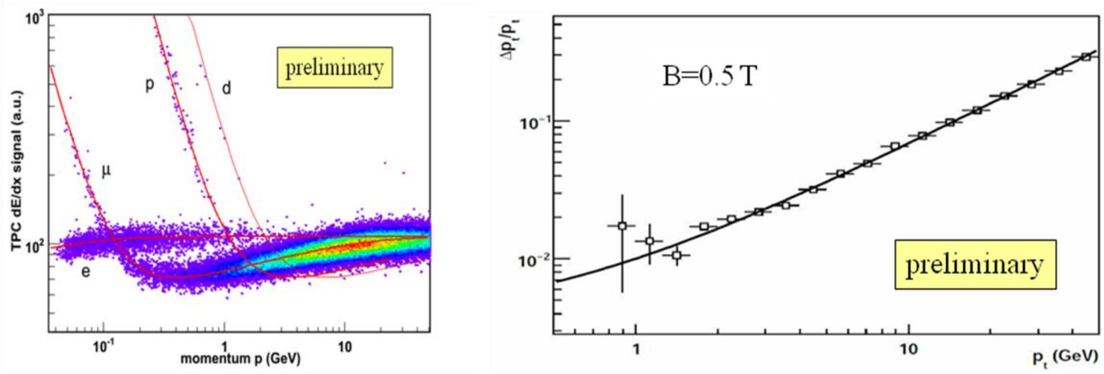

Figure 3: Left: specific energy loss in the TPC vs. momentum of the particle.
Right: transverse momentum using the TPC alone.

I will focus here on a few outstanding results from the cosmic runs, since it is impossible to cover all of them in this paper. More details on the performance of the ALICE detectors can be found in [4,5,6,7,8]. One of the most remarkable examples of the success of these runs and of the readiness achieved by the detector is shown in figure 3. With only partial calibration, the measured dE/dx resolution of the TPC is 5.7%, to be compared with a goal set in the Physics Performance Review (PPR) [9, 10] of 5.5 %. The transverse momentum resolution for the TPC stand-alone is 6.5% at 10 GeV/*c* of p_t, already close to the goal of 5% of the PPR.

One of the goals of the cosmic runs was to train the alignment procedures. In particular, the alignment of the ITS detectors is very challenging, since the target of the realignment program is that the worsening of the resolution due to misalignment shouldn't exceed 20% of the nominal resolution and the system has over 10,000 degrees of freedom. A first alignment procedure was performed applying the measurements of several survey campaigns performed on the detectors and support structures in the laboratory prior to the installation. With the dedicated pixel trigger over 10^5 events were collected with at least a track in the very small SPD detector and the so-called Millepede procedure (originally developed by V. Blobel [11]), a method for linear least squares fits with a large number of parameters, was applied. Two of the parameters used to measure the quality of the alignment are first of all the track-to-track distance in the transverse plane, obtained by treating the two halves of the track of a traversing muon as independent tracks, and, second, the residuals to the extra hit obtained when a track crosses the overlap region of two sensors. The results are shown in figure 4. When the detector resolution is unfolded, the measured residual misalignment is below 10 μm, already reaching the design goal.

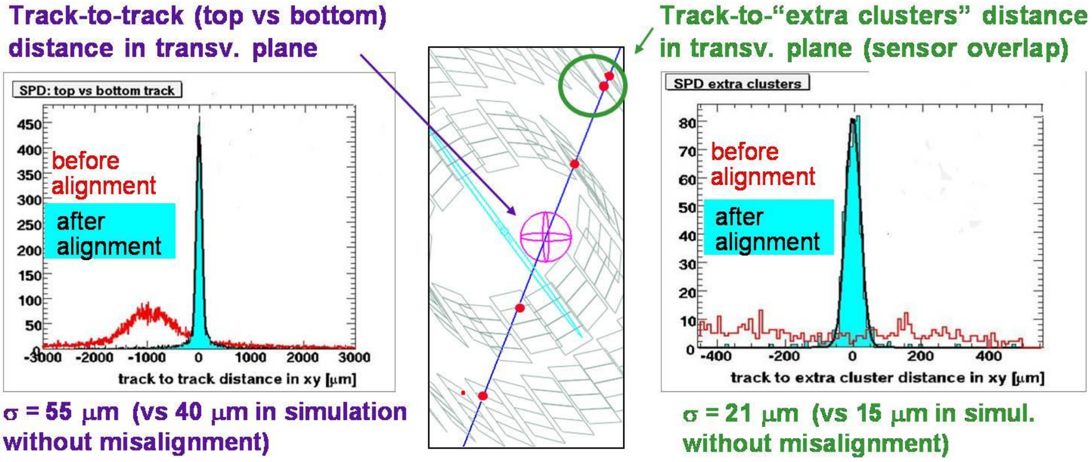

Figure 4: Alignment results for the ALICE Silicon Pixels (preliminary results)

Yet another impressive result is the time resolution measured with the TOF array. Although the number of usable tracks for this task was fairly low, about 10,000, especially compared to the 10,000 calibration parameters to be optimized, first results have shown outstanding performance. Moreover, the results are also affected by the still preliminary calibration of the other detectors involved (the TPC was used to measure the momentum of the muon and the track length between the two TOF modules). Despite this, as shown in fig. 5, a resolution of 130 ps was measured, already close to the design goal of better than 100 ps.

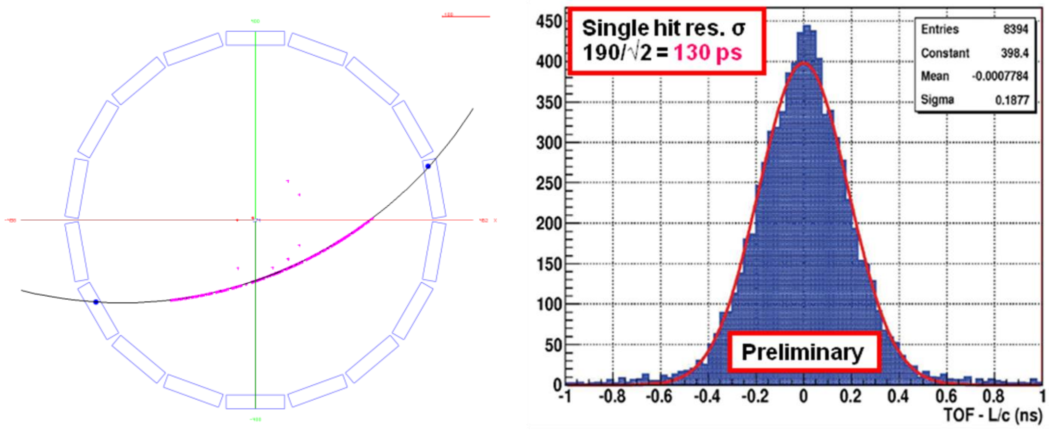

Figure 5: Configuration and results for the TOF resolution measured using cosmic muons

In addition to the runs with cosmics, already in 2008 ALICE was able to profit from the LHC accelerator test. In August and September protons were injected into the LHC and dumped at the end of the extraction line or at a collimator in the LHC. The relative timing of the ALICE trigger detectors could be studied and adjusted to allow the individual triggers to be combined into coincident trigger conditions. The particle showers emitted from the dump at the end of the extraction line provided also excellent test signals to compare the particle densities measured by the forward multiplicity detector (FMD), the silicon pixel detectors, the V0 trigger counters and the muon spectrometer. Finally, when the first particles were sent through the ALICE experiment into the next section of the LHC the first beam interaction was observed in the central tracking system. Figure 6 shows the first reconstructed event containing an interaction between a stray particle from the beam and a silicon pixel detector in the innermost layer of the inner tracking system.

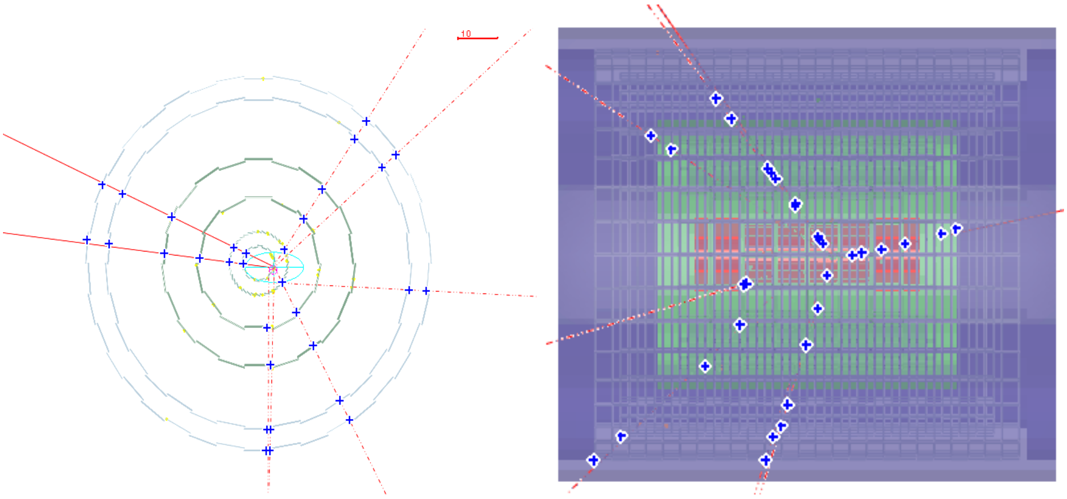

Figure 6: First event observed by ALICE during the LHC injection tests in 2008

These spectacular results clearly show that ALICE was ready to take data in the fall of 2008. The collaboration has since continued to progressively install more elements of the detectors approved at later stages (EMCal, TRD), or staged by the collaboration (DAQ, HLT), but also to improve various aspects of the apparatus. In particular, one third of the recently approved EMCal will already be available for the 2009 run. A major shutdown activity was the improvement and reconfiguration of the services on the so-called miniframe, to allow for easier maintenance of the TPC electronics and better overall accessibility. The services in general were refurbished and improved, especially from the monitoring point of view. Also the software both online and offline underwent substantial improvements which should improve the operation of the detector and ease the extraction of the first scientific results. In the summer of 2009 cosmic ray runs were resumed, and on July 11 and 12 again particles from an extraction test showered the detector, allowing a new round of timing optimizations. The detector is again operational and ready for the LHC beam.

3. Prospects for early physics with ALICE

A general discussion of the prospects of Heavy Ion Physics at the LHC is presented in these proceedings [12], so I will not address it here. I will rather give a few examples of the potential of ALICE with the very first data, to give a flavor of what we can expect in the very near future. An extensive discussion of the ALICE physics capabilities can be found in [9] and [10].

The LHC will resume operations in late 2009. At start-up some pp collisions at 900 GeV will be provided, followed by a pp run at the highest possible energy for safe operation of the accelerator. At the end of this long run, in the fall of 2010, the LHC will operate for one month with Pb beams. Therefore, when first nuclear collisions will be available ALICE will be fully commissioned, and ready to produce results.

For ALICE the pp data taking has primarily the purpose of measuring the same observables that will later be measured in PbPb collisions, in order to identify deviations from the simple superposition of pp collisions that would signal collective effects. Still, the specificities of the apparatus and of the running conditions will allow many important measurements to be performed in pp collisions that will be complementary to the ones of the other experiments. First of all, the low luminosity at which ALICE will be operated and its excellent pileup identification capability will allow the exploration of high energy densities in the small-volume regime of pp collisions by studying high-multiplicity events up to ~ 10 times the average. These measurements will be fundamental for the understanding of the large-volume high-density regime of PbPb collisions.

The very-low p_t cutoff and the particle identification capabilities of the ALICE detector will allow measurements important for the characterization of the so-called underlying event and to address specific issues such as baryon transport. Few tens of millions of minimum bias events, corresponding to approximately one month of pp running at a luminosity of the order of 10^{29} cm^{-2} s^{-1} , will already allow detailed measurements of particle compositions and spectra, with e.g. $\sim 10^6$ identified Λ and $\sim 10^4$ identified Ξ. Moreover, since most of the production is at low-p_t, the ALICE data will be essential to precisely measure the production cross section of charm and beauty mesons. As an example, figure 7 shows the ALICE measured spectrum for D^0

mesons in the Kπ decay channel for one year of pp data-taking. The importance of the very low transverse momentum cutoff is evident.

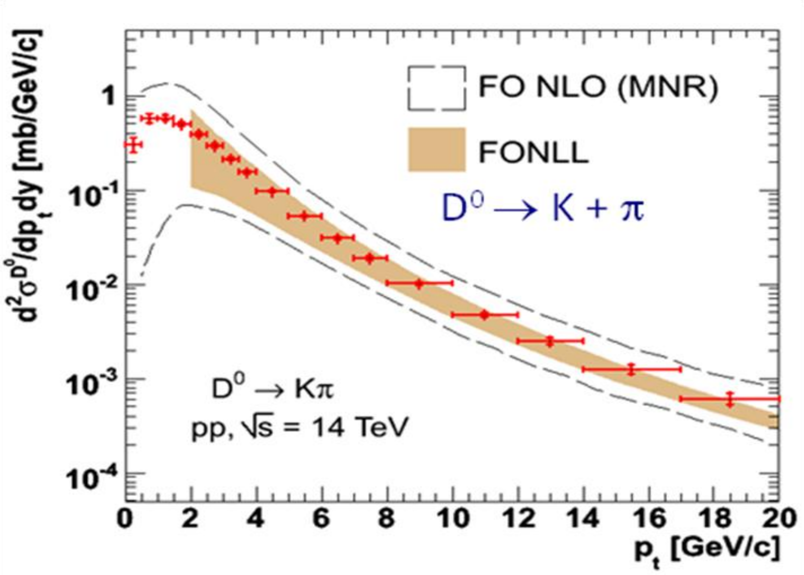

Figure 7: D^0 p_t-differential production cross sections in $|y| < 1$, in pp at 14 TeV for the statistics expected in one year of ALICE data taking, compared to NLO pQCD predictions (MNR [13] and FONLL [14]), from [15]. Error bars include both statistical and systematic errors.

It is almost a tradition for ultra-relativistic heavy ion experiments to produce important results on the fly, following the very first collisions. In fact, in 1986 the experiments at the SPS produced the first spectra, demonstrating an unexpectedly high degree of stopping and large transverse energy production, based on an accelerator test run which took place one week *before* the official start of the heavy ion run. Equally striking was the impact of the first collisions at RHIC. One week after the start of the first run in June 2000, the first paper on multiplicity distributions [16] was out, excluding 90% of the existing theoretical predictions and opening the way to concepts in which the growth in particle production expected because of the semi-hard nature of the dominant processes is tamed by saturation effects. Just two month later, based on 22k events, the paper reporting the surprising large values of elliptic flow, indicating early-time thermalization, was published [17]. In rapid sequence, after just 3 weeks of very low luminosity running and with no previous commissioning runs with proton beams, a number of fundamental papers on RHIC results appeared. Similarly, we are confident that also the LHC, when running with Pb beams, will rapidly produce scientifically valuable results. I will mention here few examples. First of all, the value of charged particle multiplicity in the central region will be measured. Already this relatively simple measurement will challenge the models, which currently describe particle production in nuclear collisions up to RHIC energies.

Figure 8 shows a collection of multiplicity results from heavy ion and p-antiproton collisions. The heavy ion data are rescaled by the number of pairs of nucleons participating in the collision, N_{part}. When extrapolating from existing data to LHC energies we see the striking difference between the results obtained applying a saturation model or a fit in $\ln^2\sqrt{s}$. As discussed in detail in [18] and [19], the multiplicity measurement will by itself force us to either revisit the central ideas used to explain particle production at RHIC or face a violation of the universal structure observed in multiparticle production at lower energies. In either case, the very first nucleus-nucleus collisions at the LHC will already profoundly influence our understanding of the field.

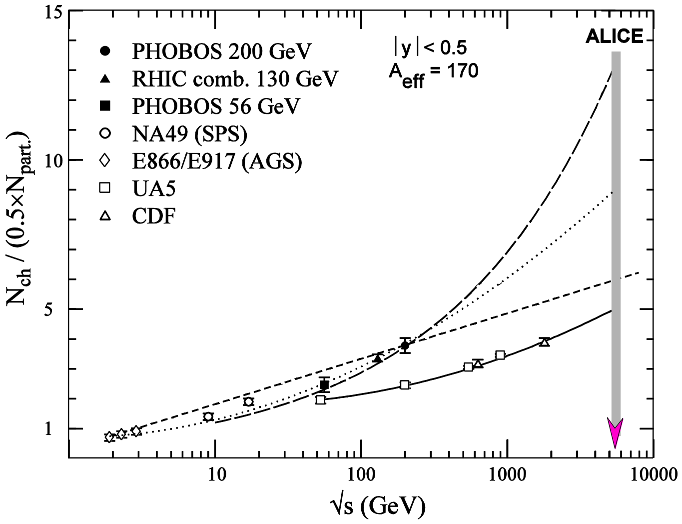

Figure 8: Charged-particle rapidity density per participant pair as a function of centre-of-mass energy for AA and pp collisions. The dashed line is a fit $0.68\ln(\sqrt{s}/0.68)$ to all the nuclear data. The dotted curve is $0.7+0.028\ln^2\sqrt{s}$. It provides a good fit to data up to 200 GeV, and predicts N_{ch} = 9 x 170= 1500 at LHC. The long dashed line is an extrapolation to LHC energies using a saturation model [20].

Another early result which will bear major consequences on our understanding of high-density QDC matter will be that of elliptic flow, or v_2, the second Fourier coefficient of the azimuthal anisotropy of produced particles. The RHIC data show a "perfect liquid" behavior, in agreement with hydrodynamic models. For the LHC, hydrodynamics would predict a modest increase of v_2, while a simple extrapolation from the data would favor a much larger value. As in the case of multiplicity, a fairly simple measurement available within a short time from the first collisions will challenge our frame of understanding of the RHIC results.

Multiparticle production in heavy-ion collisions is very well described by thermal models with very few free parameters [21], which allow the determination of the "chemical freezout" temperature, namely the temperature at which the final particle composition of the system, which expands and cools down, is fixed. This temperature, when plotted as a function of the collision energy, shows a clear saturation at T ~ 170 MeV. This limiting behavior has been interpreted as a sign that the phase transition temperature has been exceeded in the early phases of the collision. Because of the large multiplicity of produced particles, ALICE will collect within a very short time a huge sample of identified particles, allowing a precise measurement of particle composition and therefore a verification of the thermal production models. ALICE, for example, will be able to reconstruct about $3\ \Lambda$, $0.1\ \Xi$ and $0.01\ \Omega$ particles per central PbPb event and therefore collect a statistically significant sample with 10^6 central events. More generally, a sample of the order of 10^6 events will give access to most of the characteristics of the particle emitting source: particle spectra, resonances, differential flow and interferometry. As an example among many, figure 9 shows the simulated invariant mass distributions, as measured in ALICE with 10^6 central PbPb events, for the ϕ decaying to K^+K^-. The mass resolution that ALICE can achieve even with a modest statistical sample is remarkable: around 1 MeV.

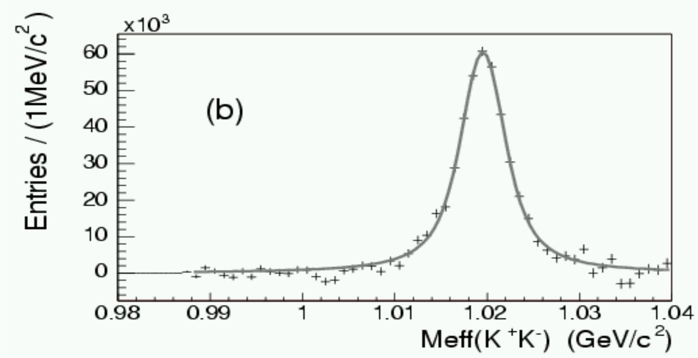

Figure 8: Example of hadronic measurements in ALICE for 10^6 central Pb-Pb events: invariant mass distributions for the ϕ going to K^+K^-.

Last but not least, due to the large increase in cross-section, the LHC will be able, already with one month of PbPb running, to collect significant data on hard processes, which probe the high-temperature strongly interacting matter generated in the collisions. These measurements, such as jet cross sections and fragmentation functions and production of heavy quarkonia and heavy mesons, will be rapidly within reach at the LHC. To quote just two examples, with 10^6 central PbPb events ALICE will be able to reconstruct over a thousand jets with energy larger than 100 GeV, while with 10^7 events the measurement of the D^0 in $K\pi$ will reach a significance of ~ 40.

4. Conclusion

The ALICE experiment has been successfully commissioned during the 2008 and 2009 runs. All of the detectors underwent extensive tests and calibrations. First results with cosmic rays show performance figures which are very close to the design values. The experiment is ready and promises to produce exciting results already from the very beginning of the pp run, expected in late 2009. Moreover, the LHC with Pb beams will allow ALICE, even with its first run, to perform fundamental new measurements, shedding new light into our understanding of strong interactions.

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