

# Status of the ALICE experiment at the LHC

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The status of the ALICE experiment is presented. ALICE is the LHC experiment devoted to heavy ion collisions. Preparing for the first lead-lead run, foreseen in November 2010, ALICE is successfully collecting data in proton-proton collisions at the LHC since November 2009, exploiting the characteristics of the detector for its proton-proton physics program. First results are briefly reviewed with an emphasis on performance of its detector sub-systems.

## I. INTRODUCTION

ALICE [1, 2] is a general-purpose heavy ion experiment designed to study the physics of strongly interacting matter and the quark-gluon plasma in nucleus-nucleus collisions at the LHC. Its physics program shaped the detector design which has specific features compared to other LHC detectors. ALICE is actually designed to cope with the highest particle multiplicities for Pb-Pb collisions (at the design time a value of  $dN_{ch}/dy$  up to 8000 was foreseen), providing excellent particle identification capabilities in a wide range of energies (0.1-100 GeV).

At the LHC the energy for nucleus-nucleus collision will be 30 times [3] the highest reached at RHIC. This will in turn correspond to a factor 2 in the temperature reached by the fireball and an increase from 5-10 GeV/fm<sup>3</sup> up to 15-60 GeV/fm<sup>3</sup> in terms of critical energy. The lifetime of the QGP will extend from 1.5-4.0 fm/c up to 10 fm/c. The study of the QGP is thus expected to enter into a new domain, with many hard signals much more available at the LHC energies (a factor 100 increase is expected for  $b\bar{b}$  production [4], for example).

As a main design guideline ALICE wants to measure the flavor content and momentum phase distribution event-by-event. Consequently ALICE has to track and identify most (within  $2\pi \cdot 1.8\eta$  units) of the hadrons from very low momenta ( $< 100$  MeV/c) to study soft processes up to fairly high  $p_T$  ( $\approx 100$  GeV/c). The vertex recognition of hyperons and D/B mesons must be operated in an environment of very high charged-particle density. Dedicated and complementary systems for di-electrons and di-muons and a devoted detector to measure centrality must be in place. Photon detection and electromagnetic calorimetry has been implemented in specific regions of angular acceptance.

The ALICE detector [5] can be broadly described by three groups of detectors: the central barrel, the forward muon spectrometer (DIMUON) and the forward detectors. The central part of the detector measures hadrons, electrons and photons on an event-by-event basis. It covers polar angles from  $45^\circ$  to  $135^\circ$  over the full azimuth and it is embedded in the large L3 solenoidal magnet operated at  $B=0.5$  T. The central barrel consists of: an Inner Tracking System (ITS) of high-resolution silicon detectors, a cylindrical Time-Projection Chamber (TPC), a Transition Radiation Detector (TRD) for electron identification, a Time-Of-Flight (TOF) detector and a single-arm ring imaging Cherenkov detector (HMPID) for hadron identification. Two single-arm electromagnetic calorimeters (PHOS and EMCAL) complement the characterization of each event. The forward muon arm (covering polar angles  $180^\circ - \theta = 2^\circ - 9^\circ$ ) consists of a complex arrangement of absorbers, a large dipole magnet, and fourteen planes of tracking and triggering chambers. Several small detectors (ZDC, PMD, FMD, TZERO and VZERO) for global event characterization and triggering are located at forward angles. During the first LHC period of operations ALICE has full hadron and muon capabilities, with the relevant detectors fully installed and operational. TRD, PHOS and EMCAL detectors have been partially installed and their completion is foreseen during the first long LHC shutdown.

Data collection is proceeding smoothly thanks also to the excellent performance of the LHC accelerator. Preparing for lead-lead collisions ALICE aims to collect in 2010 1 billion of proton-proton minimum bias (MB) events. Differently from hard processes, the particle production in soft interactions is not well-established in QCD and phenomenological models are used. Even at LHC energies a significant fraction of the produced particles doesn't originate from hard scattering processes and it is therefore needed to collect data in order to tune these models and provide a solid baseline picture to then study heavy ion collisions. ALICE, with its unique particle identification capabilities and low momentum reach, can in particular complement similar studies made by other LHC experiments during the early

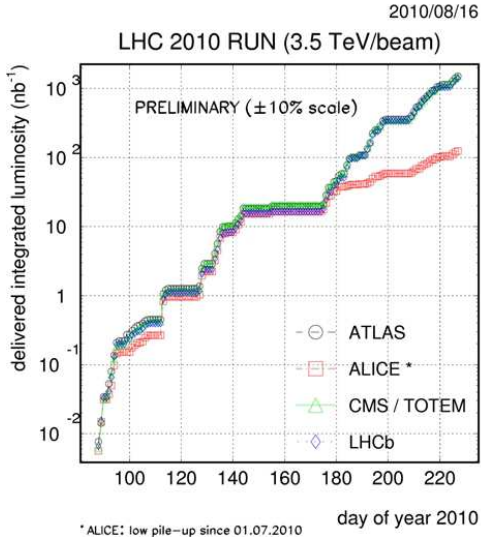


FIG. 1: The integrated luminosity delivered at the four LHC experiments as of 16 August 2010. Note ALICE low pile-up settings since beginning of July.

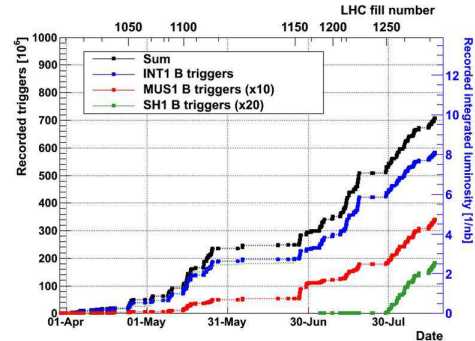


FIG. 2: Data collection in ALICE for the different trigger types.

data collection at the LHC.

The MB trigger requires a hit in the SPD or in either one of the VZERO counters; i.e. essentially at least one charged particle anywhere in 8 units of pseudorapidity. The MB trigger is complemented by the coincidence with the signals from two beam pick-up counters, one on each side of the interaction region. The SPD (the ITS innermost detector) surrounds the central beryllium beam pipe (3 cm radius, 0.23% of a radiation length) with two cylindrical layers (at radii of 3.9 and 7.6 cm, 2.3% of a radiation length) and covers the pseudorapidity ranges  $\eta < 2$  and  $\eta < 1.4$  for the inner and outer layers, respectively. VZERO counters consist of two scintillator hodoscopes. They are placed on either side of the interaction region at  $z = 3.3$  m and  $z = -0.9$  m. They cover the regions  $2.8 < \eta < 5.1$  and  $-3.7 < \eta < -1.7$ .

The integrated luminosity delivered to the four LHC experiments is shown in Fig. 1. It is worthwhile to note that since beginning of July 2010 the luminosity at ALICE point of interaction has been reduced to keep the pile-up within the TPC less than 5%. The data collected so far for the different type of triggers are shown in Fig. 2. Besides the discussed MB trigger (INT1B), a devoted trigger for the di-muon spectrometer (MUS1B) is in place. It requires, in addition to the MB trigger, at least 1 hit in three of the four triggering layers of the di-muon detector with some geometrical alignment request, corresponding currently to an effective cut of  $\sim 0.5$  GeV/c in transverse momentum of the selected tracks. Since the beginning of August a high-multiplicity trigger (SH1B), again based on the SPD and requiring at least 65 hits firing in the detector, has been activated.

Section 2 of this paper highlights some key performances results. Section 3 presents some early physics results but with an emphasis on the detector capabilities which made them possible. A full overview of the first physics results is instead presented at this conference in [6] and the ALICE physics program for heavy ions in [7].

## II. PERFORMANCE

The Inner Tracking System (ITS) of ALICE consists of six silicon layers, the two innermost abovementioned pixel detectors (SPD), two layers of drift detectors (SDD) and two outer layers of strip detectors (SSD), which provide up to six points for each track. The design spatial resolutions of the ITS sub-detectors ( $\sigma_{r\phi} \times \sigma_z$  are:  $12 \times 100 \mu\text{m}^2$  (SPD),  $35 \times 25 \mu\text{m}^2$  (SDD) and  $20 \times 830 \mu\text{m}^2$  (SSD)).

Fig. 3 shows the impact parameter resolution for reconstructed tracks in ALICE satisfying standard TPC track

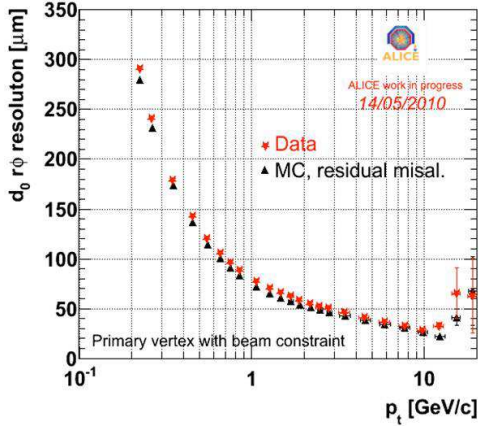


FIG. 3: Impact parameter resolution in the SPD as a function of transverse momentum.

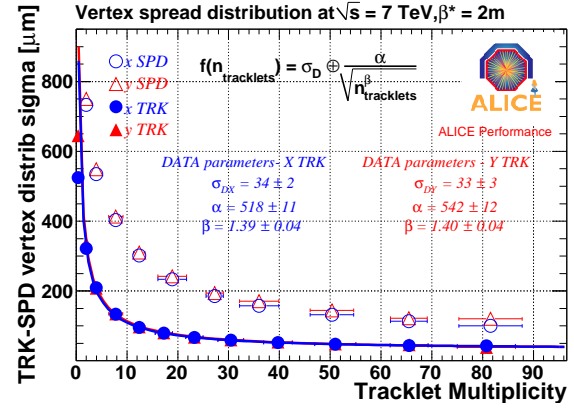


FIG. 4: Vertex spread measured by ITS (SPD) and ITS and TPC (TRK) reconstructed tracks.

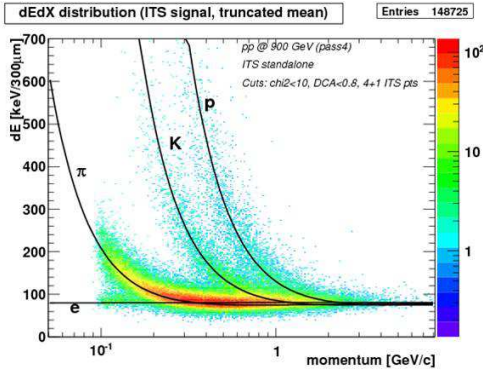


FIG. 5: Particle Identification provided by ITS via  $dE/dx$  measurement.

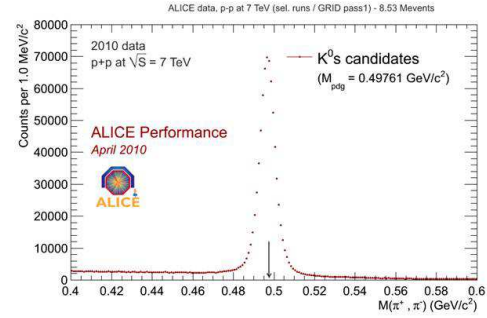


FIG. 6:  $K_s^0$  invariant mass.

quality cuts (basically a number of TPC clusters greater than 70) and having two points in the SPD. For each track, its impact parameter was estimated with respect to the primary vertex reconstructed without using this track. The resulting resolution is the convolution of the track-position and the primary-vertex resolutions. While the difference with the Monte Carlo shows that the residual misalignment is already below  $10 \mu\text{m}$ , the resolution of  $50 \mu\text{m}$  achieved at  $2 \text{ GeV}/c$  is critical. One of the main items of the ALICE physics program is the measurement of charm and beauty hadron production in Pb-Pb collisions. To measure the separation from the interaction vertex, of the decay vertices of heavy flavoured hadrons, requires a resolution on the distance of the closest approach to the vertex well below  $100 \mu\text{m}$ .

The spread of the measured vertex position has been studied similarly using tracks reconstructed both in the TPC and the SPD and with the SPD only. The result is presented in Fig. 4. The asymptotic limit estimates the size of the luminous region ( $\sim 30 \mu\text{m}$  for both projections) seen for the vertices reconstructed with tracks. The vertex resolution depends on the event multiplicity. It can be parametrized as  $540 \mu\text{m}/(N_{SPD})^{0.45}$  in  $x$  and  $y$  and  $550 \mu\text{m}/(N_{SPD})^{0.6}$  in  $z$ , where  $N_{SPD}$  corresponds to the number of SPD tracklets (a tracklet is built by associating pairs of hits in the two layers of the SPD). These results show the ITS is operating close to its design parameters. The ITS via measurement of  $dE/dx$  in its strip and drift detectors provides particle identification. ALICE can therefore identify particles at very low momentum ( $< 500 \text{ MeV}$ ) as shown in Fig. 5.

The TPC, 5 m long, is used to record charged particle tracks as they leave ionization trails in the Ne-CO<sub>2</sub>-N<sub>2</sub> gas. The ionization electrons drift up to 2.5 m to be measured on 159 pad rows. The position resolution is better than 2 mm. At the present level of calibration, the transverse momentum resolution achieved in the TPC is given by

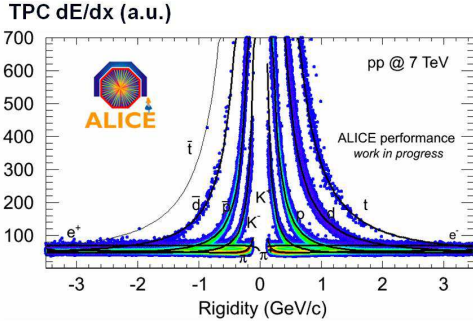


FIG. 7: Particle Identification provided by TPC via  $dE/dx$  measurement.

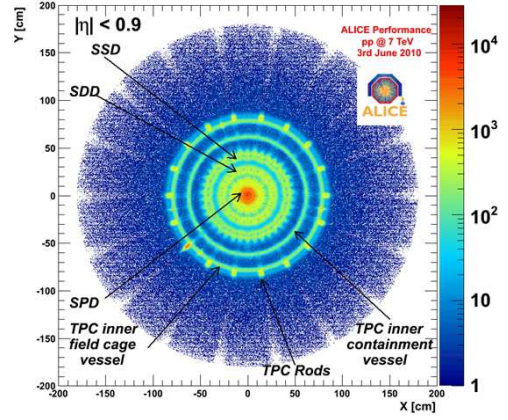


FIG. 8: Reconstructed vertices of gamma conversions, tracking  $e^+e^-$  pairs with the TPC.

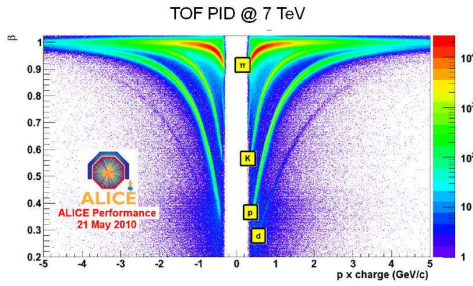


FIG. 9: Particle identification provided by TOF via  $\beta$  measurement.

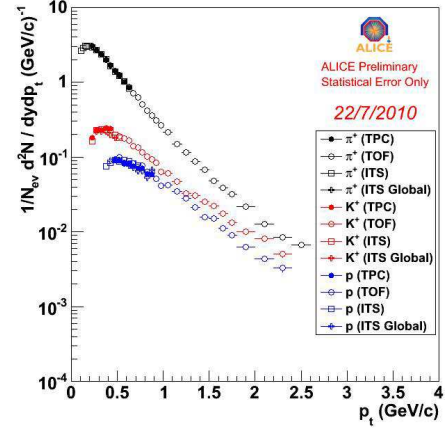


FIG. 10: Identified spectra of hadrons, using ITS, TPC and TOF information for pp collisions at  $\sqrt{s} = 900$  GeV.

$(\sigma(p_T)/p_T)^2 = (0.01)^2 + (0.007 \cdot p_T)^2$ , with  $p_T$  in GeV/c. For  $p_T > 1$  GeV/c the resolution was measured in cosmic muon events (comparing the momentum measured in the upper and lower halves of the TPC), for  $p_T < 1$  GeV/c the Monte Carlo estimate of  $\sigma(p_T)/p_T \approx 1\%$  has been cross-checked using the  $K_s^0$  invariant mass distribution which is shown in Fig. 6. The calibration of the absolute momentum scale was further verified using the invariant mass spectra of  $\Lambda$ ,  $\bar{\Lambda}$ ,  $K_s^0$  and  $\phi$ . The reconstructed peak positions agree with their PDG values within  $0.3$  MeV/c<sup>2</sup>.

The measurement of  $dE/dx$  and rigidity allows the TPC to identify  $\pi$ ,  $K$  and  $p$  at intermediate transverse momenta. The separation achieved by the TPC is shown in Fig. 7: despite the relatively low statistics it is worthwhile to highlight the clear identification of deuterons and tritium nuclei (and their anti-particles). This opens up the possibility for ALICE at LHC to successfully study in nuclei-nuclei collisions the formation of exotic hypernuclei, as reported this year by STAR at RHIC [8].

The material budget of the detector has been mapped measuring the vertex of photon conversions as tracked by the TPC. The amount of material in the central part of ALICE is very low, corresponding to about 10% of a radiation length on average between the vertex and the active volume of the TPC. Such pattern is clearly visible in Fig. 8 where the three different silicon detectors, the segmentation and the support structure of the TPC are precisely identified. The current simulation reproduces the amount and the spatial distribution of reconstructed conversion points in great detail, with a relative accuracy of a few percent. Such knowledge of the detector has been key to keep

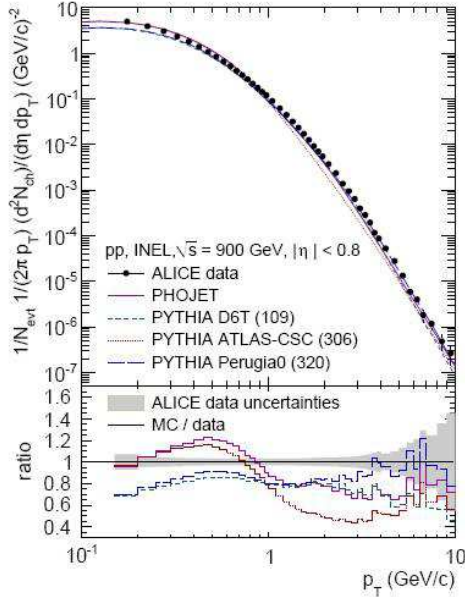


FIG. 11: Charged particle differential yield compared with various models. Bottom: ratio Monte Carlo/data.

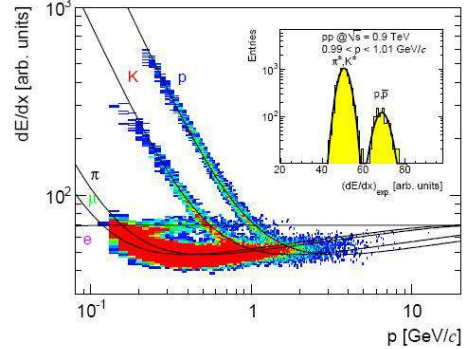


FIG. 12: Measured ionization per unit length in the TPC for  $\bar{p}/p$  ratio analysis (see text).

under control systematic uncertainties while measuring the  $\bar{p}/p$  ratio.

The particle identification capabilities of ALICE are extended at higher momentum (up to 2.5 GeV/c for pions and kaons and up to 4 GeV/c for protons) by the TOF detector, a large (144 m<sup>2</sup>) Multigap RPC array with resolution below 100 ps at current level of calibration. Its performance is shown in Fig. 9, where the separation between the different hadrons is clearly visible, including deuterons. Preliminary spectra of identified positive hadrons, using the information from ITS, TPC and TOF are shown in Fig. 10 for data taken at  $\sqrt{s} = 900$  GeV. Despite it is still a preliminary result, this plot shows neatly the good understanding of sub-detectors and inter-calibration issues. Other cross-checks have been exploited using different techniques to measure kaons spectra: charged kaons directly identified (using time of flight or dE/dx measurement) or via detection of their kink-decay topology and decay vertex reconstruction of  $K_s^0$ . Especially using the data collected at  $\sqrt{s} = 7$  TeV, identified spectra are expected to provide a baseline reference for the forthcoming measurements in lead-lead collisions.

### III. FIRST PHYSICS RESULTS AND CONCLUSIONS

ALICE has already published physics results about charged particle multiplicity at  $\sqrt{s}=0.9$  [9], 2.36 [10] and 7 [11] TeV. The ITS and TPC detectors, coupled with the discussed MB trigger, are at the basis of these results. The measured value at the highest energies are significantly higher than that obtained from current models and tunes. This fact may be interpreted as a good news for heavy ions physics: at LHC we could expect a hotter and dense medium in lead-lead collisions. Transverse momentum spectra of charged particles at  $\sqrt{s} = 0.9$  TeV [12] shown in Fig. 11 provided further insights about required Monte Carlo tuning: while it is possible to change some parameters to obtain one or two of the observed features it is more complicated to reproduce all observed characteristics. The full set of ALICE observables (including identified spectra for  $K_s^0$ ,  $\Lambda$ ,  $\Xi$ ,  $\phi$ ) not only will help to tune Monte Carlo parameters, but will shed hopefully further light on our understanding of soft QCD.

ALICE studied also the  $\bar{p}/p$  ratio [13] at  $\sqrt{s}=0.9$  and 7 TeV at mid-rapidity and  $0.45 < p_T < 1.05$  GeV/c. Its results set tight limits on additional contributions to baryon-number transfer over very large rapidity intervals with respect to standard models. Experimentally, besides the precise mapping of material budget already discussed, this result is grounded on the excellent PID capabilities of the TPC in the specified momentum range, as shown in Fig. 12

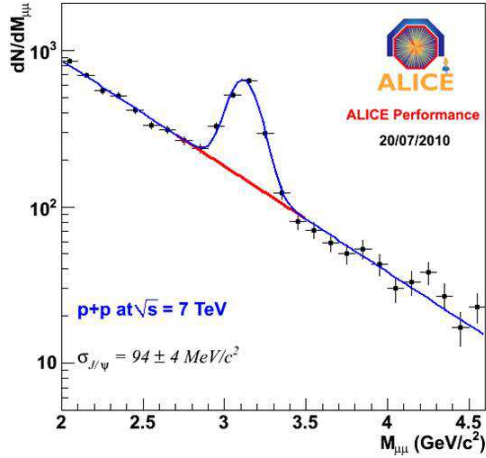


FIG. 13:  $J/\Psi$  reconstructed mass with muon pairs selected in the forward muon spectrometer.

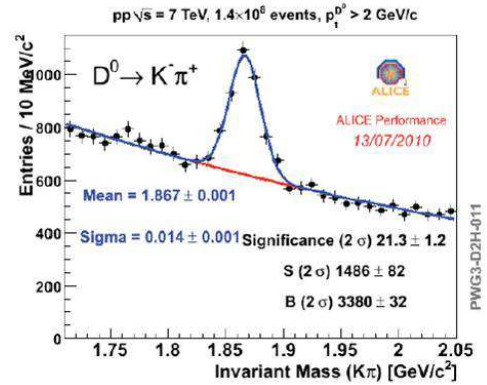


FIG. 14:  $D^0$  mass reconstructed in the barrel using ITS, TPC and TOF information.

(the inset shows the measured ionization for tracks with  $0.99 < p < 1.01$  GeV/c with Gaussian fits to the data).

Discussed tracking, momentum and PID performances are also at the basis of preliminary results related to  $J/\Psi$  spectra (using the forward muon spectrometer) and identification of open-charm mesons decays in the barrel shown respectively in Fig. 13 and 14. The alignment procedure played also a key role: the width of the  $J/\Psi$  peak moved from an initial value of  $240$  MeV/ $c^2$  to  $95$  MeV/ $c^2$  with a target design resolution of  $70$  MeV/ $c^2$ .

In conclusion, during the first months of operation of the CERN-LHC, ALICE is taking data smoothly and with all its detectors in operation. At the time of the conference more than 700 millions of triggers were taken, with a recorded integrated luminosity of  $10$  nb $^{-1}$ . Real collisions allowed to check if ALICE 'fits for purpose'. As shown, most sub-detectors are at or close to design parameters. The calibration, intercalibration and understanding of different detectors is in continuous progress.

The ALICE detector is now eagerly waiting for heavy ion collisions: the energy reached at LHC will allow the study of the Quark Gluon Plasma in a new domain. The physics analysis for proton-proton collisions is well under way with results already published for multiplicity, Bose-Einstein correlations [14],  $p_T$  spectra,  $\bar{p}/p$  ratio and a wide range of analyses is on-going. The unique PID capabilities and low  $p_T$  reach in ALICE are being exploited in forthcoming analyses.

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- [1] ALICE Collaboration, J. Phys. G, 30, 1517 (2004).
  - [2] ALICE Collaboration, J. Phys. G, 32, 1295 (2005).
  - [3] R. Vogt, Nucl. Phys. A752, 447 (2005)
  - [4] M. Mangano, R. Vogt and S. Frixione (editors), CERN Yellow Report, CERN-2004-009, 247 (2004).
  - [5] ALICE Collaboration, J. Instr. 3, S08002 (2008).
  - [6] Jan Fiete Grosse-Oetringhaus for the ALICE Collaboration, these proceedings (2010).
  - [7] Claude Pruneau for the ALICE Collaboration, these proceedings (2010).
  - [8] STAR Collaboration, Science, 328, 58 (2010).
  - [9] ALICE Collaboration, Eur. Phys. J. C, 65, 111 (2010).
  - [10] ALICE Collaboration, Eur. Phys. J. C, 68, 89 (2010).
  - [11] ALICE Collaboration, Eur. Phys. J. C, 68, 345 (2010).
  - [12] ALICE Collaboration, Phys. Lett. B, 693, 53 (2010).
  - [13] ALICE Collaboration, Phys. Rev. Lett., 105, 072002 (2010).
  - [14] ALICE Collaboration, Phys. Rev. D, 82, 52001 (2010).