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Summary Talk

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Abstract. A brief summary of the contributions to the conference *Heavy Ion Collisions in the LHC Era*, held in Quy Nhon, Vietnam, from July 16th to 20th 2012, is provided together with some personal comments. Contributions are classified according to their link to the different stages of a high-energy heavy-ion collision.

1. Introduction

This contribution aims at providing a concise summary, together with some personal comments, of the talks presented in the conference *Heavy Ion Collisions in the LHC Era*, held in Quy Nhon, Vietnam, from July 16th to 20th 2012. The classification of the 38 talks according to different subjects, related with the different stages of a heavy-ion collision, is shown in Fig. 1. Of them, 14 are experimental talks and 24 theoretical ones. All in all, they provide an nice overview of the whole field of Heavy-Ion Physics at high energies. I will refer to the different contributions by the family name of their presenters. The overview presentation by *Blaizot* will not be summarized.

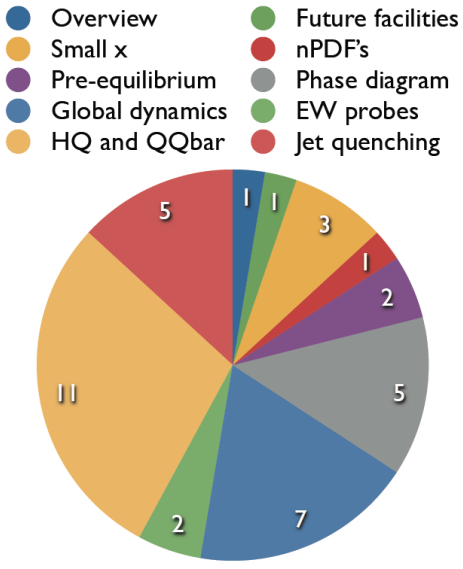

Figure 1. Distribution of the talks in subjects.

2. Initial state and pre-equilibrium

The understanding of the initial conditions for a heavy-ion collision and the path towards a collective behaviour is of major importance in the field. Equally important is the matter of the existence of a new regime of QCD in which non-linear dynamics is dominant - usually named saturation regime, for which the CGC framework has been developed. All these aspects have been treated in the conference.

2.1. Small-x physics

Nayak presented a brief overview of the status of small-x physics in hadronic and nuclear collisions, focusing mainly on the successful description of multiplicities, and nuclear suppression factors and two-particle correlations at forward rapidities. He showed the upgrade plans of ALICE, focused on the forward calorimeter FoCal that would be installed during LS2 (around 2017) and provide forward coverage (up to $\eta = 5.5$) for jets, π^0's and γ's.

Fujii presented the most recent developments in the CGC to compute single inclusive particle production, and specifically discussed the predictions for pPb collisions at the LHC with the rcBK Monte Carlo. Predictions from this approach are found to differ from those of collinear factorization only in the forward region. Uncertainties in the formalism, both from the order in the perturbative calculations and from the treatment of impact parameter, were addressed.

Beuf revised the theoretical status of the calculation of evolution equations in the CGC. By close examination of the kinematics in the higher order corrections, he proposed a simple modification to account for finite energy corrections. This is an important step towards a more reliable phenomenology in the field.

2.2. Nuclear parton densities

Helenius showed a way to introduce impact parameter dependence in any set of nuclear parton densities by expanding the nuclear dependence in powers of the profile function of the nucleus. This is a long waited step, badly needed for phenomenology. He showed the results of such procedure for EPS09. Noticeably, the results for nuclear modification factors for minimum bias and for central collisions are found to be quite close.

Armesto presented the proposal of an electron-ion collider at CERN in the TeV regime, the Large Hadron Electron Collider that implies building an electron accelerator. He showed the the large capabilities of such a machine for determining nuclear parton densities, establishing the QCD dynamics at small x and other aspects of interest for high-energy heavy-ion collisions.

2.3. Pre-equilibrium dynamics

Itakura discussed the importance of high-intensity fields in the different areas of physics. He proposed that high magnetic fields created in non-central heavy-ion collisions would induce vacuum birefringence, which could generate elliptic flow and higher harmonics in the azimuthal distributions, and distorted images in interferometry, of photons.

Ipp discussed the role of the high QCD fields created in the collision in the fast isotropisation required for hydrodynamical models to describe the experimentally observed features of data like transverse momentum and azimuthal distributions. He showed how anisotropies in the initial state lead to instabilities and the evidences that these instabilities, in the case of an expanding system, quickly isotropise it.

3. Phase diagram

During recent years, impressive progress in lattice calculations and their comparison with experiment has been done, together with new ways of exploring the phase diagram, both theoretically and experimentally, in search of its phase structure. All these aspects have been covered in the conference.

Gupta reported on the recent, impressive progresses of lattice computations in characterizing the phase diagram of QCD. The search of the critical point through the study of moments of distributions of different particles has made possible a first direct contact between lattice and experiment. The importance of finite size corrections was also discussed.

On the other hand, *Zhuang* showed how effective models can be used to explore the region of large baryon density and the connections that appear with condensed matter physics. Specifically, he presented a NJL model with isospin chemical potential, and the resulting rich structure with a BEC→BCS transition.

Asakawa discussed the formalism of moments and its connection with lattice quantities, and the uncertainties in such connection. Concretely, he addressed the fact that in lattice baryon number fluctuations are studied, while experimentally protons are measured. He concluded that final state interactions via resonances do not spoil the connection.

Then two experimental talks were devoted to the search of the critical point. *Blume* reviewed the searches of the critical point via energy and size scan at the SPS (in NA45): particle ratios and their fluctuations versus energy, and multiplicity fluctuations. With a strong ongoing debate on how conclusive the observations are for indicating or ruling out the existence of the critical point, he also presented the future prospects of these searches in NA61 at the SPS or CBM at FAIR.

Finally, *Llope* reviewed the results of the systematic beam-energy scan (BES) at RHIC from 7.7 to 200 GeV per nucleon and the lack of evidences of a non-monotonic behaviour of the cumulants of particle distributions. The future prospects to set these conclusions on firmer ground, lie in increasing statistics and making a finer scan in energies.

4. Global dynamics

An impressive amount of data on global dynamics, particularly on particle azimuthal distributions both from RHIC and the LHC, is becoming available. All these data, reported at the conference, challenge current global models for heavy-ion collisions. New developments, both at qualitative and quantitative level, were also presented.

Yoo revised the ALICE results on multiplicities, which show agreement with expectations from saturation models, and on azimuthal distributions. Data on many Fourier moments and for identified particles thanks to ALICE unique PID capabilities, are now available up to quite large transverse momentum. They strongly indicate the need of refined event-by-event initial conditions for collective evolution.

Shi revised the results on elliptic flow of the BES at STAR, in search of non-monotonic behaviours to define the phase boundary or critical points. The main conclusion are that the difference between particles and antiparticles (showing breakdown of scaling in the number of constituent quarks) decreasing with increasing beam energy is suggestive of the importance of hadronic interactions at the lowest studied energies. ϕ elliptic flow shows a non-monotonic behaviour with energy.

Niida showed results on different Fourier components for identified particles in PHENIX at top RHIC energy, and about two particle correlations with flow subtracted. The results offer strong constraints on hydrodynamical models and on the jet-medium interaction.

Turning to the phenomenological side, *Werner* showed recent improvements in the EPOS model motivated by the measurements of two particle correlations - the ridge - at RHIC and the LHC. By studying regions of different energy density and for different energy losses of particles, regimes of hydrodynamical evolution, of hard particle (jet) production and of jet-medium interaction are defined. In this way, the model is able to describe a wealth of experimental data, and gives an explicit example of how complex modeling heavy-ion collisions is.

Jeon showed the results of the MUSIC event generator that solves event-by-event viscous hydrodynamics. He showed how viscosity quickly smooths the irregularities present in the event-

by-event initial condition, and how shear viscosity reflects on the different Fourier coefficients.

More on the theoretical aspects, *Bhalerao* showed how important the specific realization of viscous hydrodynamics is for the description of data. He discussed how to derivate it from kinetic theory including non-local terms in the Boltzmann equation.

Finally, *Q. Wang* discussed the calculation of transport coefficients using perturbative techniques, including elastic and inelastic (radiative) processes. He showed the discrepancies existing in different calculations - some of them seeming able to describe the fast isotropization that hydrodynamical models need to describe experimental data, some of them not - and localized where the discrepancies came from.

5. Hard and electromagnetic probes

Hard probes is a hot topic in the field due to the possibility of characterizing the medium produced in heavy-ion collisions, either directly the temperature and energy density, or its transport coefficients. Both these aspects and the required benchmark measurements were discussed in this conference. The most recent theoretical ideas and phenomenological implementations were presented.

5.1. Electro-weak probes

Benhabib showed the results on Z and W production in pp and PbPb collisions at the LHC using the CMS detector. Such extraordinary results constitute a test of the validity of the Glauber model and start to offer constraints on nuclear parton densities, particularly through $W^{\pm}$ asymmetries. The extension of these studies to pPb collisions looks very promising, provided the statistics are large enough.

Campbell showed the PHENIX results on photons, both in the high transverse momentum domain where they constitute a benchmark measurement and perturbative techniques are successful, and at low transverse momentum where they show hints of thermal emission that are currently used by models to extract the initial temperatures and energy densities of the medium. She also showed the elliptic flow of photons, that at large transverse momentum is small and compatible with perturbative expectations, while at low transverse momentum is very large and defies existing theoretical explanations.

5.2. Heavy quarks and quarkonium

Kim revised the use of quarkonium as a 'thermometer' of the medium through sequential melting of resonances as suggested by lattice and potential models. Then the CMS data on suppression of higher states of the Υ family in PbPb compared to pp, strongly suggestive of such sequential melting, were shown. The results on prompt J/ψ were also presented, indicating suppression of b quarks. Finally, the new, surprising results about enhancement of $\psi(2S)$ over J/ψ at small transverse momentum and suppression at larger transverse momentum, were discussed and the uncertainties of the measurement indicated.

Bastid showed the ALICE results on heavy quarks, both from direct measurements and from semileptonic decays, and quarkonium, in several channels and at different rapidities. Charmed mesons are suppressed in accordance with current models of energy loss, while the situation for charmonium is very complex. It seems very difficult to understand present data without some amount of recombination, and the role of shadowing of nuclear parton densities has to be established before quantitative conclusions can be extracted from data.

Bona showed the already quite old results from ATLAS in PbPb collisions. On the other hand, new extremely nice results in pp were discussed, providing both tests of pQCD and spectroscopic information. One can only lament that such a wonderful detector suffers such lack of manpower.

Qiu showed the STAR results on J/ψ including v_2, which indicate negligible flow within uncertainties, and on Υ's. On heavy flavors, the evidences from a large b-decay contribution to non-photonic electrons, and the new measurements that reconcile the results from STAR and PHENIX about the charm cross section, were discussed together with the excellent possibilities offered by the Heavy Flavor Tracker for heavy flavor studies in the future.

On the theory side, *J. Wang* revised the recent progress in computations of quarkonium hadroproduction in non-relativistic QCD. He showed the advances in including different singlet and octet contributions for different states, not only for the cross sections but also for the polarization. He discussed the different strategies of the different groups to fit the available parameters. He demonstrated how the polarization puzzle remains and how it demands new data from the LHC and, eventually, the inclusion of relativistic corrections.

Bianchi discussed J/ψ polarization in pp collisions at the LHC in ALICE, indicating how it constrains different models and that none of them really works. Studies at larger transverse momentum are required in this respect, as present data are restricted to rather low values. Finally, he addressed the point of how these measurements are relevant for heavy-ion collisions as assumptions on the (unmeasured) polarization in PbPb collisions are required and they affect sizably the extracted cross sections.

Back on phenomenology, *Nahrgang* discussed the effects of medium modeling on heavy quark propagation in a QCD medium. He showed the amount of ingredients: production, medium modeling with realistic evolution, equation of state, mechanisms of energy loss,..., that have to be considered. He discussed the effect of event-by-event fluctuations in medium modeling that seem to have a modest effect, and how models that work confronted to RHIC data fail for the LHC, and vice versa.

Ferreiro discussed the importance of cold nuclear matter effects, particularly the unknown nuclear modifications of parton densities, for quarkonium hadroproduction. He showed the interplay between cold nuclear matter effects and the detailed microscopic mechanism of hadroproduction and how pPb data at the LHC can help to clarify the situation.

Casalderrey discussed a most nice, simple model for quarkonium evolution using a Schrödinger equation with different potentials. Understanding the fate of a $Q\bar{Q}$ pair in medium is crucial to characterize it. The model offers information about the interplay of the different characteristics of the medium for the different states.

Ko presented a model for quarkonium production in heavy-ion collisions, which considers production, medium evolution through hydrodynamics, different in-medium potentials for quarkonium dynamics, and regeneration. He discussed how several models successfully describe experimental data and how the amount of details required in the implementation depend on the chosen setup. Event-by-event fluctuations do not seem to have a large effect on this observable.

Finally, *Krein* revised the different aspects that must be considered in order to understand the interaction of J/ψ with nuclear matter. This issue is of interest both intrinsically for non-perturbative QCD and for the use of quarkonium suppression as a QGP signature. The different open problems, and the different experimental proposals to study it in antiproton annihilation on deuteron in the Panda experiment at FAIR, and in electroproduction in ATHENNA in JLab, were presented.

5.3. Jet quenching

On the experimental side, *Di Nezza* revised ALICE results on particle production at large transverse momentum at the LHC, both for charged particles (single inclusive distributions and back-to-back correlations) and for jets, for which ALICE offers valuable information complementary to that from ATLAS and CMS. The problems for reconstruction of the latter were discussed. While charged hadrons are in agreement with current models, jets offer intriguing features that remain to be confirmed and understood, together with the problems for their

reconstruction in a large heavy-ion background.

On the phenomenological side, *Peigné* reviewed a calculation of how QCD radiation affects quarkonium production in a way that cannot be simply described by energy loss. Interferences between initial and final state radiation lie at the heart of the discussion, and the results were implemented in a model which successfully reproduces data of quarkonium absorption in pA collisions at fixed target energies and at RHIC. Data from pPb collisions at the LHC will be crucial to further clarify the relevance of these ideas.

Salgado revised the new developments on radiative energy loss of fast partons in a QCD medium. He discussed the limitations of presently used models, and reported on the ongoing work to understand QCD branching in a colored medium. This should constitute the basis for jet calculus in a medium and, as such, the basis for a rigorous implementation of multiple emissions in Monte Carlo models for QCD branching. While waiting for applications to jet physics at the LHC, this is a key aspect in order to make reliable extractions of medium parameters through hard probes.

Bluhm revised one of the aspects usually neglected in current models of radiative energy loss, namely how the presence of an absorptive medium may affect the radiation from a fast parton - a subset of the next-to-leading effects to be considered. He showed that radiation may be strongly reduced for some values of the parameters. While the effect may become parametrically large, going beyond parametric estimates is crucial for applications to phenomenology.

Arleo revised the use of γ+heavy quark production as a tool to constrain nuclear effects on parton densities in pA, and for determining medium properties in AA - with the photon coming from fragmentation and the heavy quark being affected by the colored medium. Again, pPb collisions at the LHC will be most useful to validate these studies, particularly if statistics are large enough.

6. To conclude

The conference has shown a large variety of results that illustrate the richness of the field. The pPb run [1] in January-February 2013 (the pilot run on September 13th 2012 has already resulted in 3 publications [2, 3, 4]), together with the future ion runs [5], the upgrade plans of the different experiments, and the projects for electron-ion colliders [6, 7], indicate how active the field is and evidence its bright medium term future.

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