The Next Decade of Physics with PHENIX

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Abstract. The first decade of RHIC physics and the first heavy ion running at the LHC have produced a wealth of data and discoveries. It is timely to now evaluate what has been learned and ask what compelling new questions have been raised. In this talk, several key unanswered questions about the properties of the strongly coupled quark gluon plasma and the distribution of partons inside nucleons and nuclei will be discussed along with how they can be addressed experimentally. The PHENIX Collaboration has developed a plan for upgrading the experiment in order to address these new questions. The current status of these plans will be presented.

1. Introduction: The First Decade of PHENIX

The main goal of the heavy ion program at the Relativistic Heavy Ion Collider (RHIC) is to produce and study the quark gluon plasma. The first decade of RHIC running have been very successful. The collaborations have established that a new form of matter was created [1]. The study of that matter, the strongly interacting quark gluon plasma (sQGP), has led to an emerging picture of matter which behaves hydrodynamically and is nearly opaque to hard partons.

As a community, we are now working toward building a coherent understanding of the sQGP. The RHIC collaborations were asked to develop plans for the next ten years of RHIC operations. These proceedings report on the current status of the PHENIX Decadal Planning process. The complete Decadal Plan, submitted in October 2010, is available here [2].

2. New Questions in Heavy Ions

As a vital part of planning for the future the PHENIX Collaboration discussed what compelling questions remained after the first decade of RHIC running and what new questions have been raised by our current knowledge. Within the realm of heavy ion physics five compelling questions were identified:

- are quarks strongly coupled to the QGP at all distance scales?
- what are the detailed mechanisms for parton-QGP interactions and responses?
- are there quasiparticles at any scale?
• is there a relevant screening length in the QGP?
• how is rapid equilibration achieved?

For the first two questions, jets, including heavy flavor tagged jets are an essential tool to probe the matter. The screening length is addressed by high quality quarkonia measurements. One observable relevant to the final question is the $v_2$ of direct photons. In the time since the Decadal Plan was written PHENIX has submitted such a measurement for publication [3]. Additional observables sensitive to equilibration are under discussion.

2.1. Hard Probes at RHIC in the Age of the LHC

In November 2010 the Large Hadron Collider (LHC) took Pb+Pb data for the first time at $\sqrt{s_{NN}}=2.76$ TeV. Many results from the ALICE, ATLAS and CMS Collaborations were shown at this conference. Given the lower collision energy at RHIC, it is natural to ask what role hard probes, especially jet measurements, play at RHIC.

The question of the mechanisms by which hard probes interact with the sQGP is open despite very detailed measurements from the first decade of RHIC data. With the large difference in energy density at the two machines RHIC and LHC together can help resolve this puzzle more effectively than either can alone. As the LHC experiments repeat measurements that had been previously done at RHIC (such as single particle $R_{AA}$ measurements), new insights are gained. Similarly when high quality jet measurements in heavy ion collisions are done at RHIC, the insights gained from LHC jet results will be tested and refined. Here jet measurements refers to a broad class of measurements that include not only single jet suppression factors, but also reconstructed dijet correlations, heavy quark jets and $\gamma$-jet correlations. A coherent understanding of parton-matter interactions will be able to describe these observables across a wide range of energy densities.

3. sPHENIX Detector Concept

The central driver for the sPHENIX mid-rapidity detector design is jet measurements. The sPHENIX detector philosophy rests on three points: large rate, large acceptance and large calorimetric coverage. While this philosophy is central to jet measurements in high energy physics experiments, this combination does not currently exist at RHIC.

A cartoon drawing of a strawman sPHENIX design is shown in Fig. 1. The existing Barrel Silicon Vertex detector (installed for the 2011 RHIC Run) and the Forward Vertex Detector (to be installed in Summer 2011) are retained from the present PHENIX design. Additional silicon tracking at a radius of $\approx 40$ cm is added to improve the momentum resolution and track finding capabilities. The central magnet is currently envisioned to be a 2T solenoid. Simulations performed suggest that this should be sufficient to separate the $\Upsilon_{2S}$ and $\Upsilon_{3S}$ states from the $\Upsilon_{1S}$. The electromagnetic calorimeter concept involves a preshower as part of the electron identification and $\pi^0$ reconstruction [2].
While the calorimeter would be very compact, a small Molière radius ($R_M \approx 2\text{cm}$) design leads to reasonable occupancies in central Au+Au events. The hadronic calorimetry is a central part of the jet measurements, providing the best possible measurement of the jet energy and the fluctuations in the underlying event and prevents fake high momentum tracks from seeding fake jet signals.

Specific technology choices had to be used in the strawman design in order to do realistic simulations, however the actual technology choices are still under active discussion. The design of the forward rapidity upgrades is discussed further in Ref. [2].

The sPHENIX goal is to be able to take nearly the entire delivered luminosity for hard probes in heavy ion collisions. Based on luminosity projections we anticipate something on the order of 50B events sampled in a Au+Au run. Notably, $\approx 25B$ minimum bias events could be recorded. This vast data sample provides rates to do not only light flavor jet measurements, but also di-jet measurements, heavy quark tagged jets, $\gamma$-jets and quarkonia.

Figure 2(left) shows the rates for jets, $\pi^0$s, direct photons and heavy quarks expected in central Au+Au events. Plotted on the y-axis is the number of counts expected per event for $p_T \geq p_T(cut)$ where $p_T(cut)$ is the value on the x-axis. Specifically, if one wants on order of 1000 counts for the various channels this allows light quark jets up to about 60GeV/c and $\approx 30\text{GeV/c}$ for charm and bottom jets (provided they are able to be tagged). Fig 2(right) shows the acceptance increase from the current PHENIX acceptance to the sPHENIX acceptance given a pseudo-rapidity acceptance of $|\eta| < 1$. 

\textbf{Figure 1.} A strawman sketch of the sPHENIX detector. Some features of the detector are discussed in the text.
Acceptance increases by factors of 10 to nearly 100 are seen for various probes.

4. Conclusions

The sPHENIX plan provides a detector that is well matched to compelling heavy ion physics goals. Additionally, RHIC is a collider known for its versatility. This detector is well matched to polarized p+p and d+Au collisions to study the spin structure of the nucleon and the cold nuclear matter effects as well. Future goals in these programs especially constrain the forward capabilities of this detector and are discussed in detail in the Decadal Plan [2]. Additionally, as part of an electron ion collider this detector could be used for some e+A and e+p measurements as well.

Precision jet measurements in heavy ion collisions at RHIC will be complementary to those taken at the LHC. Having two machines at well separated collision energy, both with the rates, acceptance and detectors capable to study hard probes such as jets and quarkonia provides excellent opportunities to gain insight into the puzzles that now exist, particularly energy loss and screening lengths and be ready to confront new surprises.

5. References

[1] Adcox K et al. 2005 Nucl. Phys. A757 184–283
[2] PHENIX 2010 The phenix experiment at rhic: Decadal plan 2011-2020 URL http://www.phenix.bnl.gov/plans.html
[3] Adare A et al. (PHENIX) submitted to Phys. Rev. Lett. (Preprint 1105.4126)