Title: Development of the Electromagnetic Calorimeter for the sPHENIX Experiment at Relativistic Heavy Ion Collider at Brookhaven National Laboratory

Instrumentation Research Proposal (5 Pages Total)

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1. Introduction (1 Page)

Writeup: In the early 2000s, a type of hot and dense quantum chromodynamics (QCD) matter called quark-gluon plasma (QGP) was discovered at high-energy nuclei collisions at the Relativistic Heavy Ion Collider (RHIC) and was also created at the Large Hadron Collider (LHC) in the 2010s. The temperature can reach trillions of Kelvin in relativistic heavy-ion collisions. Nucleons will "melt" and become QGP. The constituents of QGP, namely, quarks and gluons, strongly couple to each other via strong interaction. The strongly coupled QGP demonstrates perfect liquid properties and has sheer viscosity to entropy density ratio $\frac{\eta}{s}$ very close the strongly coupled AdS/CFT limit $\frac{\hbar}{2\pi}$. It is believed that QGP was created at several microsecond after the Big Bang. The studies of QGP will help us understand the structure of QCD phase diagram and quark-hadron transition in the early universe.

In 2015, the Nuclear Science Advisory Committee (NSAC) drafted the Long Range Plan for Nuclear Science. The Long Range Plan recommends to build the sPHENIX experiment, an upgrade to the PHENIX experiment at RHIC, to probe the inner working of QGP by resolving its properties to a shorter and shorter length scale [1]. As a complementary to LHC experiments, the sPHENIX experiment will carry out precise measurements of jet evolution, heavy-flavor tagged jet production, and precision upsilon spectroscopy to study the internal structure and medium properties of QGP at lower temperature. To achieve these physics goals, sPHENIX, the state-of-the-art large acceptance and high rate jet detector, consists of the tracking system, the calorimeter system, and the superconducting solenoid magnet from the Barbar experiment. The conceptual design of sPHENIX detector is shown as follows:

Attach sPHENIX detector here

As a member of the sPHENIX EMCAL development group, I have carried out research on the energy uniformity of 1-inch and 2-inch light guides with the 2017 test beam data at Fermi National Accelerator Laboratory for the 2017 sPHENIX calorimeter prototype and propose to get further participation on the instrumentation and simulations of the sPHENIX EMCAL. I plan to take the leadership role in the research and development of the first fully projective tungsten-scintillating-fiber SPACAL block technology and compact, high segmentation, and strong magnetic field resistive design for sPHENIX electromagnetic calorimeter (EMCAL). I am going to participate in the sPHENIX 2018 test beam at FNAL to study the MIP calibration, light guide uniformity, and energy resolution for EMCAL at high rapidity. Since we may potentially have another test beam for the calorimeter system in 2019, I may also participate in the design and fabrication of the 2019 modified EMCAL prototype with the improvement by analyzing the 2016 to 2018 test beam results. In addition to the test beam data analysis, I plan to perform Monte Carlo simulations for detector calibration and photon-jet correlations measurement as a tagged high energy parton to probe the QGP. Finally, I will build the first prototype sector of the final EMCAL and will help in the construction of the first 12 real sectors. My project will start in June 2018 and expect to finish in 2021. The end point products will be a well functioned electromagnetic detector installed in the sPHENIX detector and an simulated photon-jet correlations results expected for the actual data taking based on the detector parameters. My proposed activities of developing new calorimetry technologies for the sPHENIX experiment will have impacts on not only the sPHENIX experiment at RHIC but also on future high-energy hadron colliders like High Luminosity LHC for handling radiation damage in silicon photomultiplier and lepton-hadron colliders Electron-Ion Collider for Shashlik tungsten EMCAL design.

2. Motivation and Prior Art (1 page)

Writeup: The prior PbSc Shashlik EMCAL in the PHENIX experiment only covers central rapidity $\eta = 0.375$ with small azimuthal acceptance $\phi = \frac{\pi}{4} \times 2$ and have a finer segmentation $\Delta\eta \times \Delta\phi = 0.01 \times 0.01$. The PHENIX EMCAL is installed at $R = 5m$. The energy resolution of the PHENIX EMCAL is $\sigma(E)/E = 1.5 \oplus 8.0/\sqrt{E(GeV)}$ and the position resolution is 7mm [6]. Therefore, limited by the detector performance, the prior PHENIX experiment can only measure direct photons as bremsstrahlung or during jet fragmentation [7]. To probe the inner working of QGP to a shorter length scale, we need to be able to measure jet evolution and study jet substructure in the QGP medium. This motivates us to upgrade our EMCAL system to sPHENIX to perform these tasks. (Justification of EMCAL upgrade and what advantage of sPHENIX EMCAL compared to PHENIX EMCAL??)

The sPHENIX experiment will use jets to probe the internal structure of QGP and precise upsilon spectroscopy to measure the temperature of QGP. To be able to achieve high jet efficiency and resolution for precise measurement of heavy flavor-jet and photon-jet correlations measurements, the sPHENIX EMCAL are designed to have large coverage $\eta \times \phi = 1.1 \times 2\pi$, uniform light guide energy response, perfect energy linearity, and excellent energy resolution ($\sigma(E)/E = 1.3 \oplus 13.6/\sqrt{E(GeV)}$ at a 10 degrees incident angle from 2017 test beam data). The precise measurement of Υ spectroscopy imposes stringent requirement on the single particle energy resolution, electron identification, and electron-pion separation for the decay of $\Upsilon \rightarrow e^+e^-$. In addition, due to the fact that both the EMCAL and the inner HCAL must fit inside the solenoid magnet with enough space remaining for a tracking system, the EMCAL has a radius of 3.87 m and a compact block structure, which allows it to have large enough solid angle with minimal inactive area to enable precise measurement of jets. Finally, the high segmentation design of EMCAL $\Delta\eta \times \Delta\phi = 0.024 \times 0.024$ can resolve the high occupancy of particle shower in the calorimeter for heavy-ion collisions and measure the transverse shower shape to perform e/π rejection for the upsilon spectroscopy measurements.

In addition, the uniformity of energy response affects the energy resolution of the EMCAL. It is believed that the longer the light guide is, the better the energy uniformity is. In order to understand effects of the length of light guide on the uniformity of energy response, we measure the spatial distribution of energy of 1-inch and 2-inch light guides at a rapidity of $\eta = 1$ at 0 and 10 incident angles with the test beam from the 2017 test beam position scan run. We found that the improvement of the uniformity of 2-inch light guides was not significant compared to the 1-inch ones. Because 1-inch light guides have the advantages of lower costs and lighter weight while they have similar performance as 2-inch light guides, we decided to use 1-inch light guides in our EMCAL blocks and will test their performance again in the 2018 test beam, which will be a more realistic test of sPHENIX calorimetry performance at high rapidity.

Finally, because no sPHENIX photon-jet simulation is carried out before, I plan to carry out Monte Carlo simulation of photon-jet correlations measurement with the sPHENIX detector and the inputs from sPHENIX calorimeter test beam studies. After I finish analyzing the 2018 test beam data, I plan to apply TMVA optimization method and high performance computing to detector calibration and XXX algorithm and codes. These simulations will help us predict the sPHENIX measurement and check whether the performance of our detector design meets the physics requirements of sPHENIX or not. (Jin, can you give me some suggestion for the sPHENIX detector and physics simulations?)

Potentially, we may have 2019 test beam on the calorimeter system. I may also participate in the design and fabrication of the new EMCAL prototype and analyze the test beam data.

3. Technical Details (2 pages)