ALICE-USA Contribution

to the 2007 Long Range Plan for Nuclear Physics

1. Heavy Ions at the Large Hadron Collider and the ALICE Experiment

The Large Hadron Collider (LHC) at the European Laboratory for Nuclear Research (CERN) in Geneva, Switzerland, is scheduled to commence proton operation in 2007. The proposed injection of the LHC with lead (Pb) nuclei in 2008 will introduce a new era in the investigation and understanding of high energy density QCD. Building on studies that have been undertaken with experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in New York, heavy ions at $\sqrt{s_{NN}}$ = 5.5 TeV in the LHC will create a system at approximately twice larger energy densities (and temperatures) than achieved previously. Hard and rare probes will be approximately two orders of magnitude more abundant than at RHIC. This will allow complementary systematic studies at RHIC and the LHC for understanding the properties of QCD at high densities and the time evolution of the system.

ALICE (A Large Ion Collider Experiment) will be one of four large detector systems at the LHC. ALICE, the only dedicated heavy ion experiment, has more than 1000 scientists, engineers and technicians from 101 institutes in 29 countries working on it. In addition, the dedicated proton experiments, CMS and ATLAS, are also expected to participate in heavy ion data -taking at the LHC. ALICE will be prepared for data-taking when initial collisions become available, with protons starting either in 2007 or 2008 and Pb nuclei in 2008 or 2009 depending upon progress in commissioning the LHC. ALICE will be able to detect a broad range of particles encompassing many different observables at the LHC. ALICE expects to utilize a variety of observables that will include:

- products of hard scattering processes (jets, large transverse momentum particles and photons) as a probe to determine properties of the high temperature quark -gluon medium;
- charmonium and bottomonium production and suppression to establish the initial temperatures and the extent of deconfinement;
- particle spectra and yields in each event to determine the evolution and response of the medium to energy deposition;
- heavy flavor yields, spectra and tagged jets to extract expected differences in quark and gluon propagation;
- fluctuations in various measured quantities to extract characteristics of events .

ALICE will also investigate the extent of gluon saturation and evidence of a possible color -glass condensate at the LHC. Measurements will be made not on ly with Pb+Pb, but also p+p, p+Pb and lighter A+A systems to obtain comparison data and to understand the fundamental underlying mechanisms.

The ALICE experiment is being constructed in the large L3 magnet at CERN. It will contain a 6-layer silicon inner-tracking system and the world's largest time projection chamber for tracking and particle identification over a large solid angle at mid -rapidity. A large transition radiation detector, high resolution photon spectrometer, time-of-flight detector system and ring imaging

Cherenkov detectors supplement the particle identification for photons, electrons and high momentum hadrons. A di-muon spectrometer system will be installed at intermediate rapidities for quarkonium studies. Several US (ALICE-USA) and European institutions are proposing to construct an electromagnetic calorimeter (EMCal) to enable ALICE to trigger on and measure hard probes for detailed tomographic studies of the medium created at the LHC.

2. ALICE-USA Collaboration

The ALICE-USA Collaboration presently consists of 12 DOE-supported research institutions: Creighton University, University of Houston, Kent State University, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Michigan State University, Oak Ridge National Laboratory, Purdue University, University of Tennessee, University of Texas at Austin, Wayne State University and Yale University. The ALICE-USA Collaboration's scientific research program will focus on jet and heavy flavor probes of the produced nuclear medium. To accomplish this, a Major Item of Equipment (MIE) proposal has been submitted by the ALICE-USA Collaboration to the US DOE to construct 8 of the 11 supermodules of an electromagnetic calorimeter (EMCal) for ALICE (3 to be built by European institutions). The US proposal is progressing through DOE Review, has passed the CD-1 review stage, and the CD-2 review is expected in Summer 2007. The European component of the EMCal is also progressing through the review stage for funding in France and Italy. In October 2006, the Large Hadron Collider Committee (LHCC) approved the EMCal for installation as an integral part of the ALICE research program.

The success of the ALICE-USA Collaboration including its scientific program is contingent upon community support of the scientific program, DOE support of participation in ALICE of the ALICE-USA institutions, funding and construction of the US part of the ALICE EMCal by the DOE, and support of dedicated computing for analysis in the US of data from the EMCal.

3. ALICE-USA Scientific Approach

The observation of jet quenching and its sensitivity to properties of QCD matter are important discoveries at RHIC. The further study of jets in dense matter will play a central a role in the LHC heavy ion program and the understanding of the underlying energy loss mechanisms. It is crucial that the LHC experiments have the capabilities both to exploit the large kinematic range of jets made available by the collider and to measure jet structure and its medium-induced modification in detail. This dictates the need for efficient triggering, robust tracking and detailed particle identification capabilities down to low transverse momentum (p_T), since much of the physics related to the response of the medium is carried by soft fragments even for the highest energy jets. Tests of the physics underlying the energy loss will be made using quark jets tagged by heavy flavor decay, light hadron-led gluon jets, and γ+jet coincidences. The interaction of the jet with the medium and the response of the medium will be studied at low and intermediate p_T for a broad range of jet kinematics.

The primary scientific goal of ALICE-USA is to investigate QCD matter and measure its properties at high energy density in heavy ion collisions at the LHC. ALICE-USA will utilize the EMCal to investigate the medium modification of partonic energy loss ("jet quenching") and the response of the medium to these large depositions of energy. These measurements will focus on products of initial hard partonic scattering, such as high energy jets, photons and heavy flavors,

and lower energy particles correlated with a trigger jet or quenched jet . The EMCal, combined with the excellent tracking and particle identification capabilities of ALICE, allows unique methods to study high energy density QCD at the LHC.

The ALICE Electromagnetic Calorimeter (EMCal) adds significant new physics scope to the ALICE experiment, in particular for the study of medium–induced modification to jets as a probe of dense matter ("jet quenching"). The EMCal in ALICE enables the most extensive exploration possible thus far of jet fragmentation in heavy ion collisions. The EMCal will provide :

- an efficient unbiased *high E_T jet trigger* over a broad jet energy range in topologically complex heavy ion collisions, and efficient triggers for high p_T photons and electrons;
- detailed exploration of the *medium-induced modification of jet fragmentation* over a broad kinematic range, from the hardest jet fragments of high E_T jets to very soft fragments, when coupled with the excellent tracking and particle identification capabilities of ALICE;
- *direct photon detection*, enabling determination of the initial parton-level scattering energy prior to medium-induced modification and fragmentation of the recoil jet opposite the photon; and
- *hadron rejection* for efficient measurement of high p_T electrons, enabling studies of heavy quark jets.

The physics capabilities of the EMCal are described in the ALICE EMCal Technical Proposal to CERN (CERN-LHCC-2006-014) and the ALICE EMCal Conceptual Design Report to the DOE.

The great success of the RHIC experiments in studying complex heavy ion collisions is due in large part to a strategy of systematic comparison between collision systems. This approach relies on comparing the heavy ion results to the elementary production rates as measured in p + p collisions and provides essential cross-checks and calibrations for theoretical approaches that are necessary to extract the underlying physics. The same systematic approach will be taken at the LHC. Measurements will be made in p+p, p+Pb and Pb+Pb with identical detection systems providing comparable kinematic coverage and statistical precision for hard probes.

The EMCal is key to the measurements proposed by ALICE-USA. When coupled with measurements of the same events in other ALICE detectors, the jet measurements and triggering provided by the EMCal constitute a unique program of measurements investigating response of the medium to jet energy deposition. Control of systematic effects, and meaningful comparison of various collision systems and kinematic ranges, will require integration of the measurements from other ALICE detector systems, such as the TPC, the Inner Tracking System, and the PHOS, in order to extract the unique jet-correlation physics the EMCal brings to ALICE.

Many of the measurements in the jet program require the identification and correlation of particles inside and outside the jet cone, in order to determine medium modifications to fragmentation and properties of the QCD medium. The significantly enhanced physics reach that is accomplished with large EMCal event samples at high jet energies will allow correlations with particles in ALICE detectors that have significant particle identification capabilities, such as the TPC, TRD and PHOS. A comprehensive program also using information from these detectors will lead to the physics goals described in the previous section. The ALICE-USA collaboration will need to develop an understanding of the performance and data from these other detectors

prior to installation and data-taking with the EMCal in order to undertake correlation measurements with triggered and tagged EMCal data.

4. The ALICE EMCal

The essential design parameters for the physics performance of the EMCal are its total coverage and tower granularity. The overall acceptance of the EMCal is sufficiently large to allow a competitive jet physics program. Details of its design parameters are:

- Large effective acceptance for jets with analysis cones up to radii R = 0.5 where $R = \sqrt{(\Delta\phi^2 + \Delta\eta^2)}$ with ϕ the azimuthal angle and η the pseudo-rapidity. This is satisfied by a detector spanning 110 degrees in azimuth and 1.4 units of pseudo-rapidity.
- A photon or electron energy resolution better than or equal to $\sigma(E)/E = 15\%/\sqrt{E} \oplus 2\%$ averaged over the full detector acceptance at energies above 2 GeV and less than 100 GeV. At this resolution, the ALICE EMCal energy measurement for electrons is comparable to or better than the ALICE tracking system momentum measurement at high p_T ~30 GeV/c.
- A detector granularity and analog noise sufficient for good π^o/γ discrimination in central Pb+Pb collisions out to transverse momenta p_T ~30 GeV/c

The success of the research of the ALICE-USA Collaboration is intimately linked to the successful construction, installation and operation of the US DOE-funded EMCal in ALICE. ALICE-USA Collaboration members have leading responsibilities in the ALICE EMCal Project. The ALICE-USA Collaboration is responsible for providing the infrastructure that is necessary for 1) establishing and maintaining optimal performance of the EMCal, 2) data-taking with the EMCal, and 3) extraction of the physics associated with the EMCal in ALICE.

5. ALICE-USA Manpower

ALICE-USA presently consists of twelve member institutions. Five DOE-supported ALICE-USA institutions have initial DOE approval and support to join ALICE. These five institutions – Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, Wayne State University and Yale University – are full members of ALICE. One other institution of ALICE-USA – Creighton University – has been a member of ALICE for some time. Creighton is presently requesting DOE approval and support to participate in ALICE. The intention of ALICE-USA is that the 6 remaining DOE-supported institutions on the ALICE-USA institutional list will join ALICE sometime in FY07 after DOE review of ALICE-USA. These six institutions are University of Houston, Kent State University, Michigan State University, Purdue University, University of Tennessee and University of Texas – Austin.

The manpower table below lists the manpower commitments to ALICE-USA from the ALICE-USA institutions for the years from 2007 through 2011. These numbers represent the FTE manpower broken down by PhDs and graduate students per year. The row of "total FTEs" corresponds to the sum per year of PhDs and graduate students. The row labeled "required FTEs" corresponds to estimates from subsystem leaders of the total FTEs per year required from ALICE-USA for successful completion of tasks for EMCal detector support, EMCal trigger, computing, simulations and analysis software, and EMCal associated physics extraction (including papers). In assessing FTEs, we have used the convention that a teaching faculty member who is committed full-time for research to ALICE-USA is available only as 0.5 FTE.

Likewise, in some cases, post-doctoral fellows' partial times have been combined to attain FTE equivalence. Therefore, the actual head-count of PhDs represented by the numbers in this manpower table is significantly greater than the number of "FTEs" listed.

	2007 FTEs		2008 FTEs		2009 FTEs		2010 FTEs		2011 FTEs	
	Total		Total		Total		Total		Total	
	PhDs	Students	PhDs	Students	PhDs	Students	PhDs	Students	PhDs	Students
Subtotals	18.5	5.2	23.7	9.85	25.6	12.15	27.3	15.15	27.35	15.15
Total FTEs	23.7		33.55		37.75		42.45		42.5	
Required FTEs	23.65		32.45		38.45		43.45		45.45	