U.S. DEPARTMENT OF ENERGY

Office of Science

Office of Nuclear Physics

Science Program including LHC

October 30, 2010
Fermi National Accelerator Laboratory

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for

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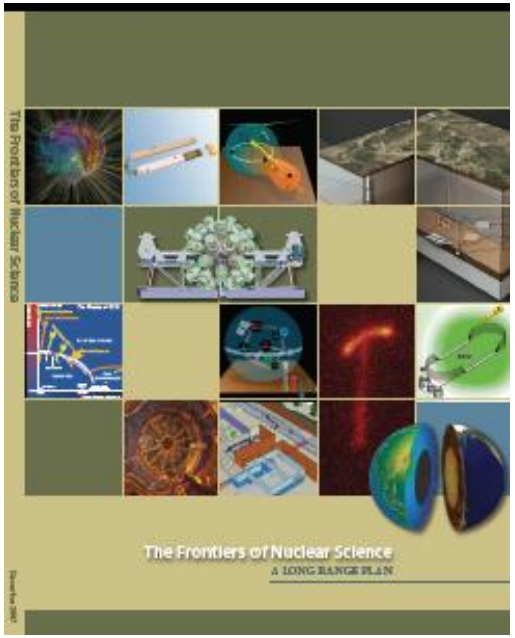
Outline

- **NP Frontiers, Mission, Priorities**
- **User Facilities, and Science Portfolio**
- **Isotopes Program**
- **12 GeV CEBAF Upgrade**
- **FRIB**
- **HI program**
  - RHIC program
  - LHC program
- **ALICE**
- **CMS**

Scientific Opportunities and Priorities

Scientific frontiers and opportunities are identified by the scientific community

- Primary guidance has come from DOE/NSF Nuclear Science Advisory Committee (NSAC)
- Other guidance obtained from National Academy of Science (NAS), Interagency/International studies, facility PACs, etc.

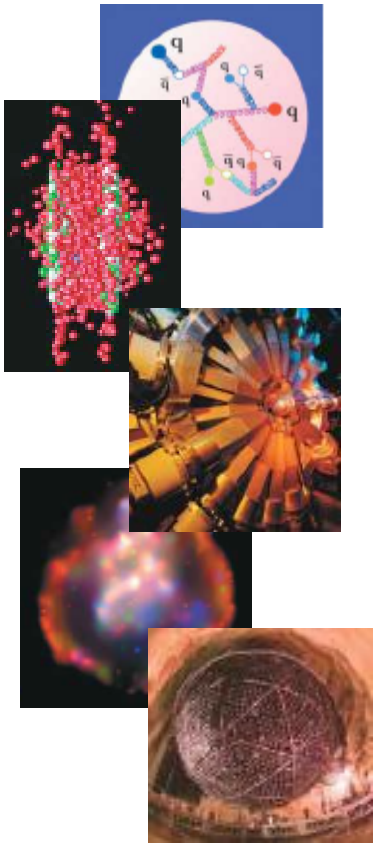


The Frontiers of Nuclear Physics

Quantum Chromodynamics
From the Structure of Hadrons
to the Phases of Nuclear Matter

Nuclei and Nuclear Astrophysics
From Structure to Exploding Stars

In Search of the New Standard Model
Neutrinos - Fundamental Interactions



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Nuclear Physics Program Mission

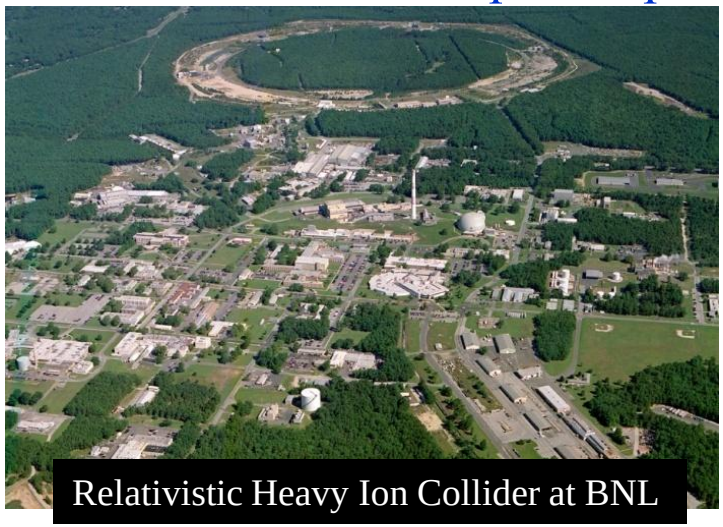
Mission: To discover, explore and understand all forms of nuclear matter; to understand how the fundamental particles, quarks and gluons, fit together and interact to create different types of matter in the universe, including those no longer found naturally

Priorities:

- To understand how quarks and gluons assemble into the various forms of matter and to search for yet undiscovered forms of matter
- To understand how protons and neutrons combine to form atomic nuclei and how these nuclei have emerged during the 13.7 billion years since the origin of the cosmos
- To understand the fundamental properties of the neutron and develop a better understanding of the neutrino
- To conceive, plan, design, construct, and operate national scientific user facilities; to develop new detector and accelerator technologies
- To provide stewardship of isotope production and technologies to advance important applications, research and tools for the nation
- To foster integration of the research with the work of other organizations in DOE

NP Operates Four National User Facilities

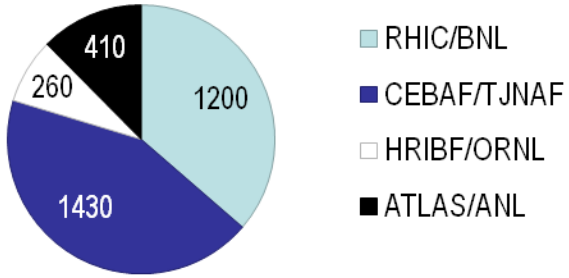
"Microscopes" capable of groundbreaking research

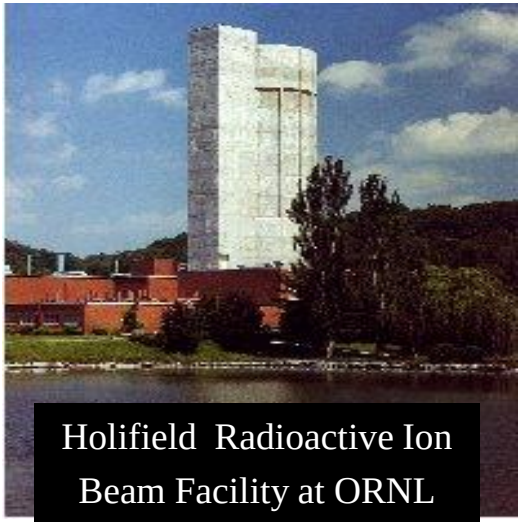


Relativistic Heavy Ion Collider at BNL

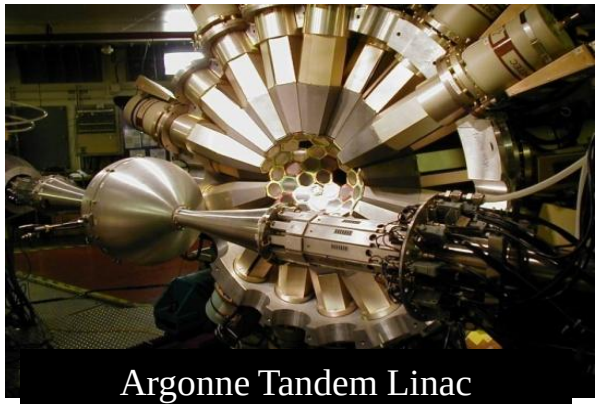
Continuous Electron Beam Accelerator Facility at JLab

Users of NP Facilities





Holifield Radioactive Ion Beam Facility at ORNL



Argonne Tandem Linac Accelerator System at ANL

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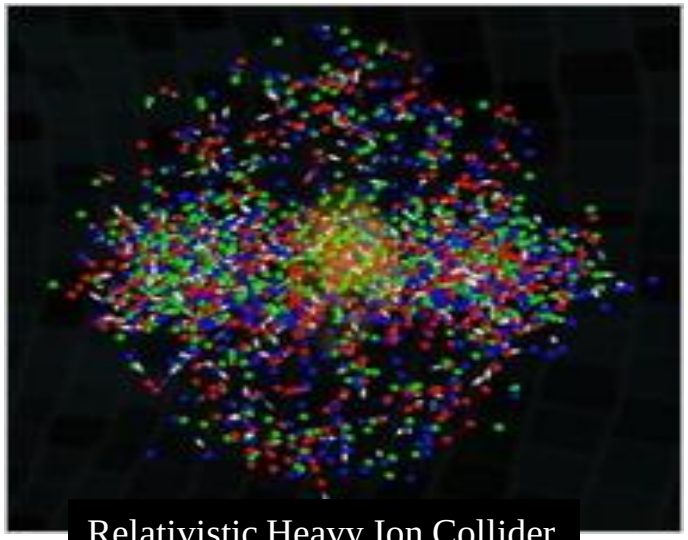
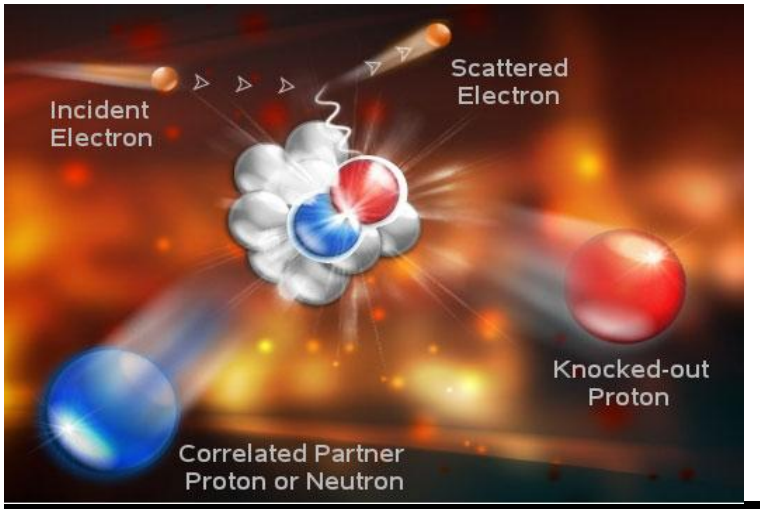
At the NP National User Facilities the Research Spans a Range of Microscopic Scales:

From Quarks and Gluons



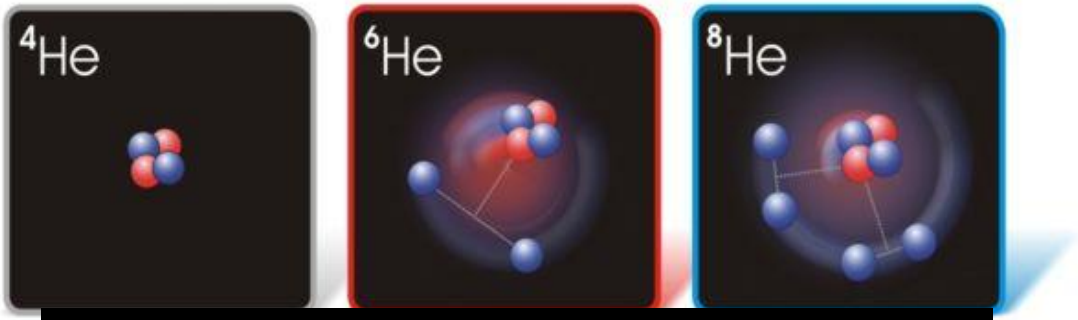
Relativistic Heavy Ion Collider

To Protons and Neutrons



Continuous Electron Beam Accelerator Facility

To Nuclei

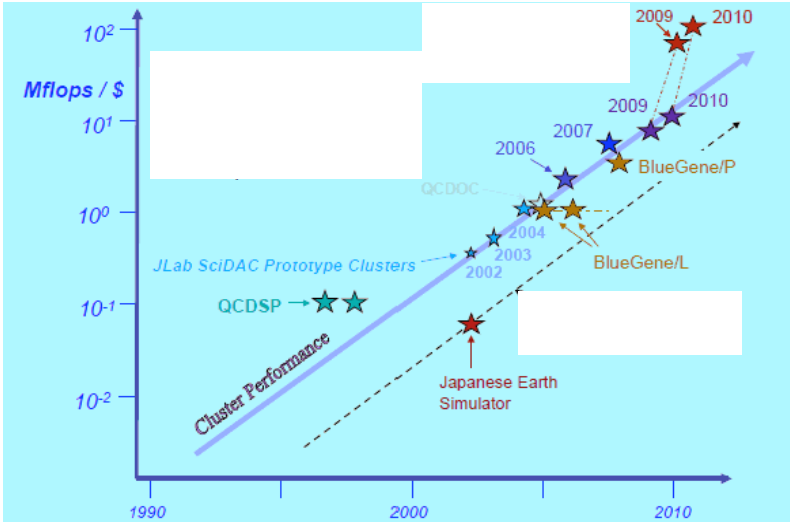


Holifield Radioactive Ion Beam Facility

Argonne Tandem Linac Accelerator System

Additional Elements of the NP Basic Science Portfolio

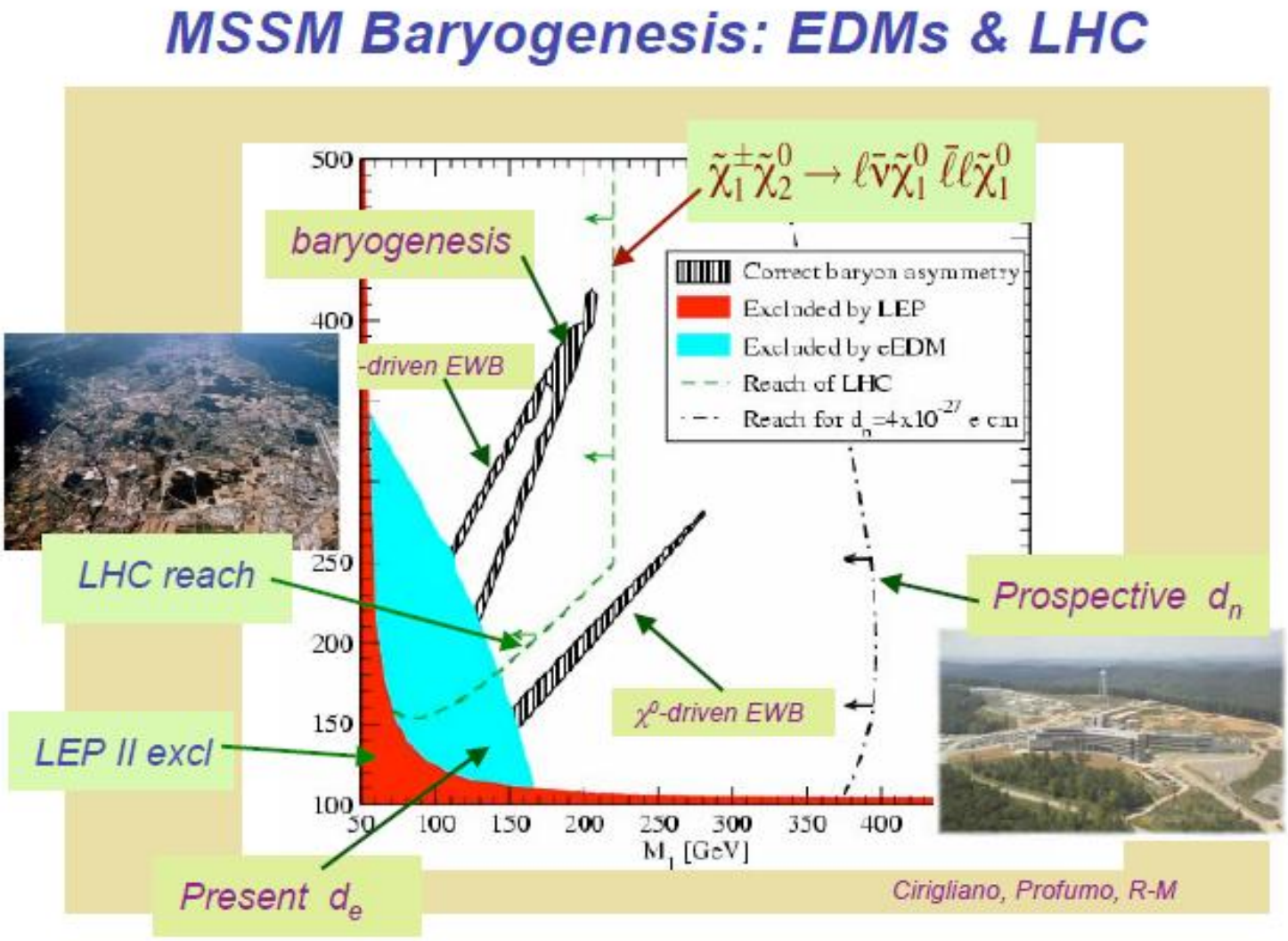
- **Nuclear Theory**
  - Effort in all areas of nuclear physics
  - SciDAC, Topical Centers, LQCD
- **Neutrino Physics-Particle/Antiparticle; Mass**
  - Cryogenic Underground Observatory for Rare Events (CUORE)
  - Majorana Demonstrator R&D
  - Karlsruhe Tritium Neutrino Experiment (KATRIN)
- **Fundamental Physics with Neutrons**
  - Fundamental Neutron Physics Beamline at SNS
  - Electric Dipole Moment of the neutron (nEDM)
  - Neutron beta-decay, reaction asymmetry, spin rotation
- **Heavy Ion Research at the Large Hadron Collider**



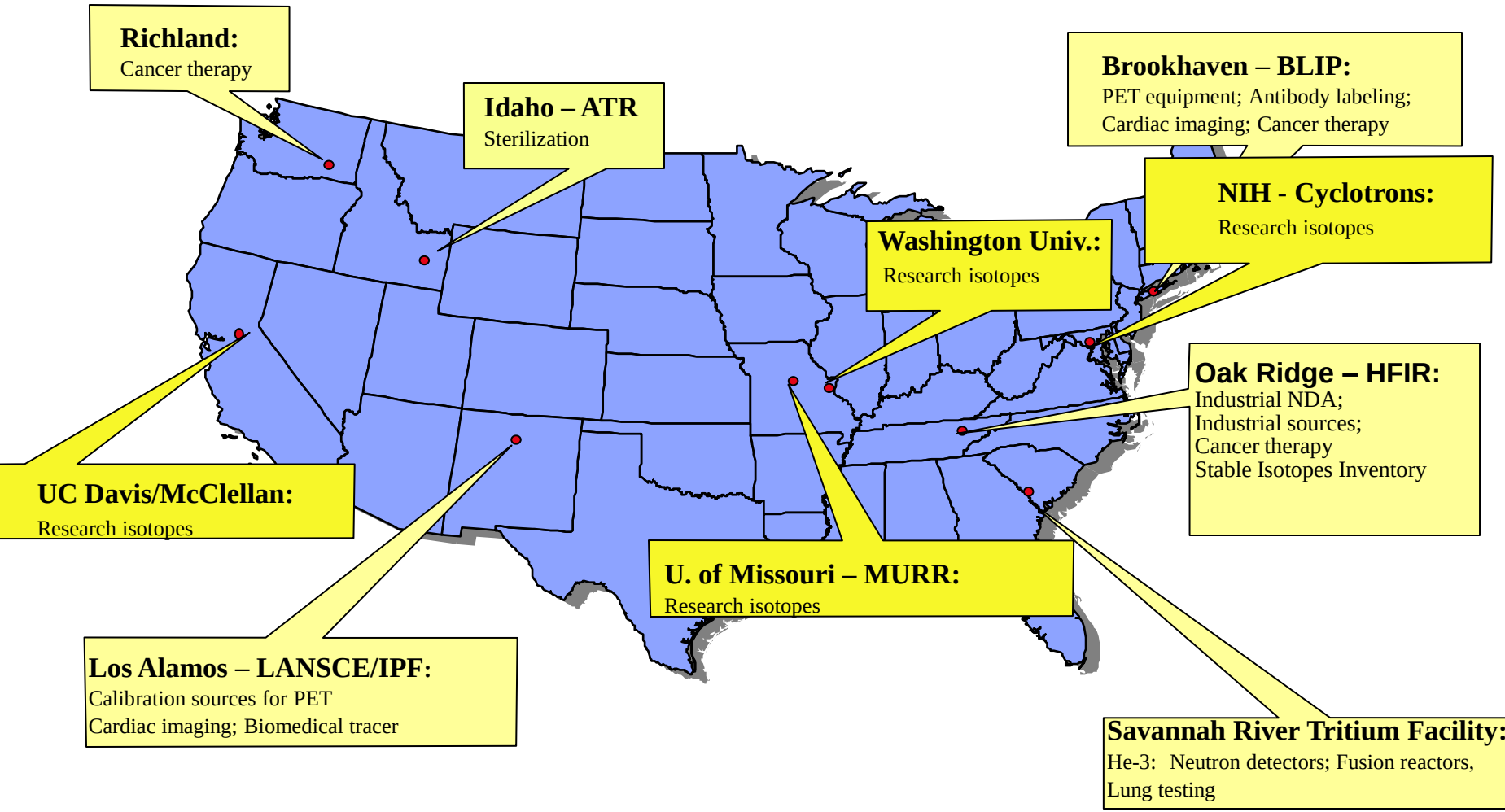
Graphical Processor Units in LQCD Computing

KATRIN Spectrometer Tank

Complementarity of High and Low Energy Approaches to Fundamental Questions



Isotope Program Production and Distribution of Commercial and Research Isotopes



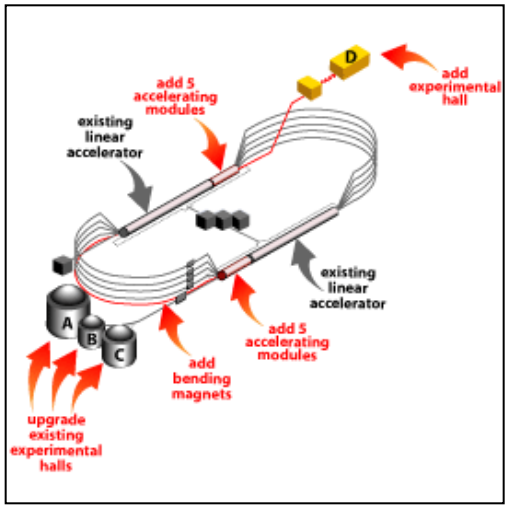
12 GeV CEBAF Upgrade Project at JLab

Unique, world-class facility and scientific program

- New insight into the structure of the nucleon
- Investigate transition between hadronic and quark/gluon description
- Address one of great questions of modern physics: the mechanism that "confines" quarks together

Scope of the project

- Doubling the accelerator beam energy
- New experimental Hall and associated beamlines
- Upgrades to the existing three experimental Halls



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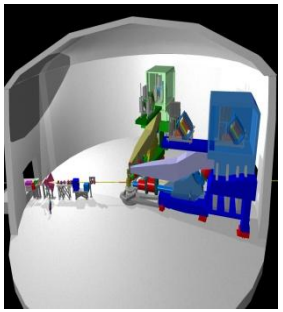
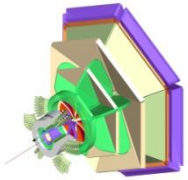


High Resolution Spectrometer (HRS) Pair, and specialized large installation experiments

TPC: $310 Million
Successful CD-2, CD-3 in FY 2008; operations anticipated in FY 2015

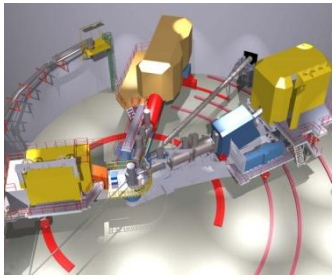
Recovery Act funding advances project funding of $65 Million

B



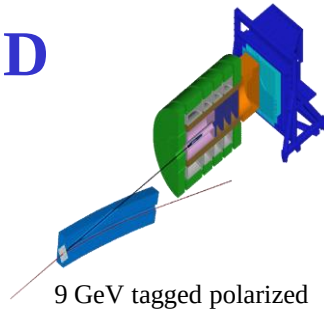
CLAS upgraded to higher (10^{35}) luminosity and coverage

C



Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles

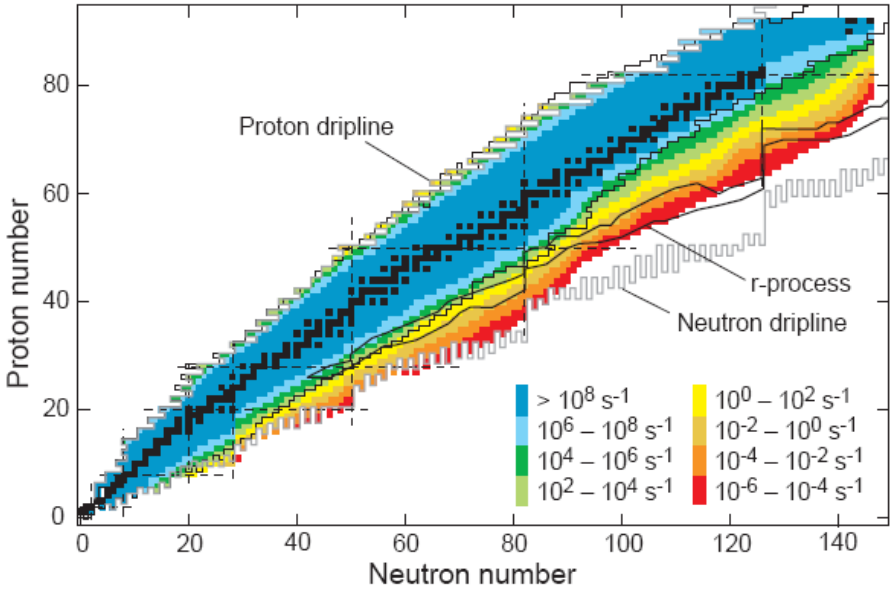
D



9 GeV tagged polarized photons and a 4π hermetic detector

Facility for Rare Isotope Beams (FRIB) at MSU

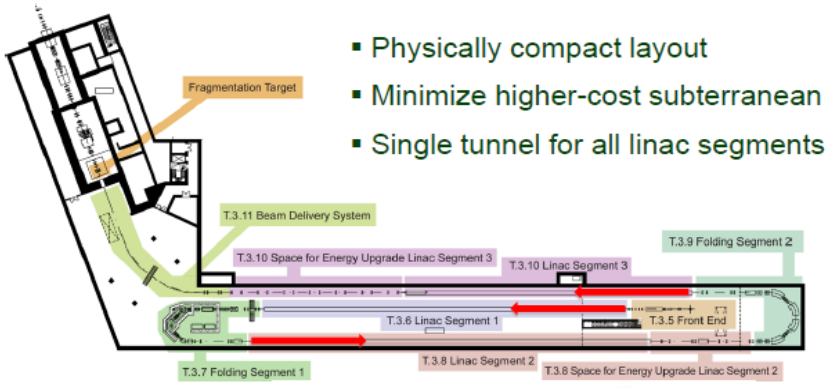
Production of Rare Isotopes



FRIB at Michigan State University

Science Drivers for FRIB

- **Nuclear Structure**
- **Nuclear Astrophysics**
- **Fundamental Symmetries**
- **Other Scientific Applications**



- Physically compact layout
- Minimize higher-cost subterranean structures
- Single tunnel for all linac segments

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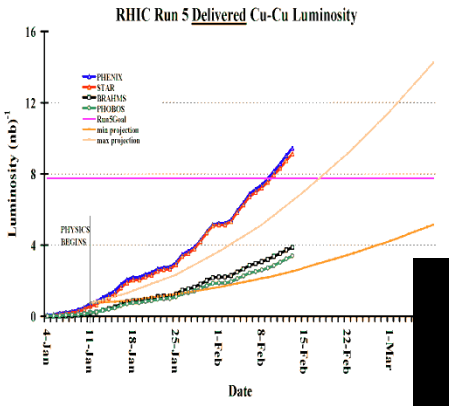
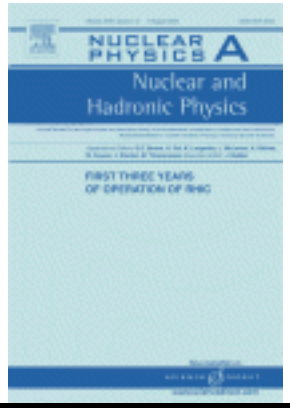
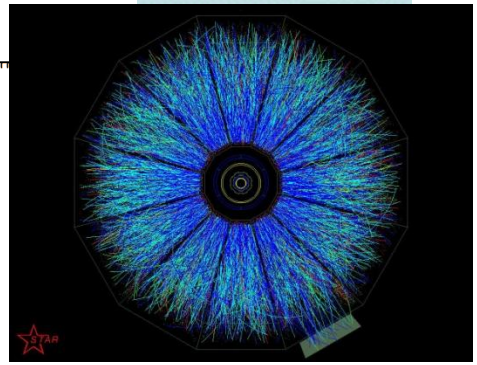
Research at the Relativistic Heavy Ion Collider

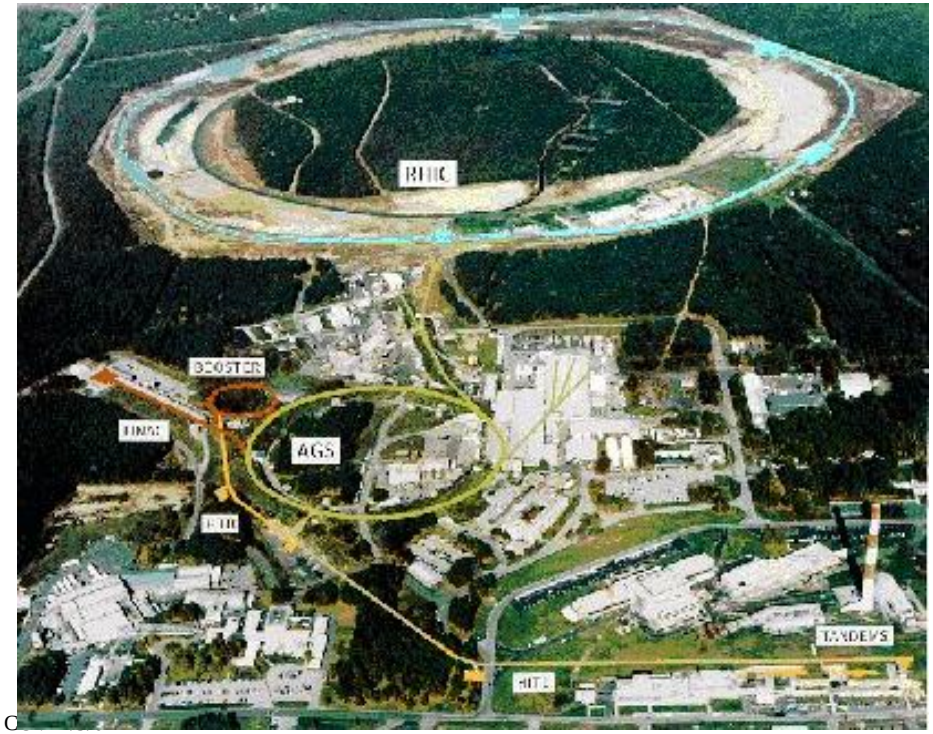
Capabilities:

- Relativistic Heavy Ion Collider at BNL
- RHIC completed in 1999; first physics in 2000
- Serves an international community of ~1200
- Colliding beams: Gold (to 100 GeV/nucleon)
  Protons (to 250 GeV)
- EBIS begins commissioning 2010







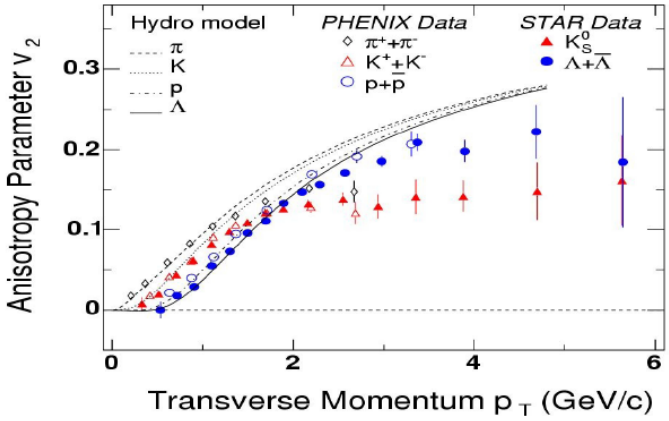


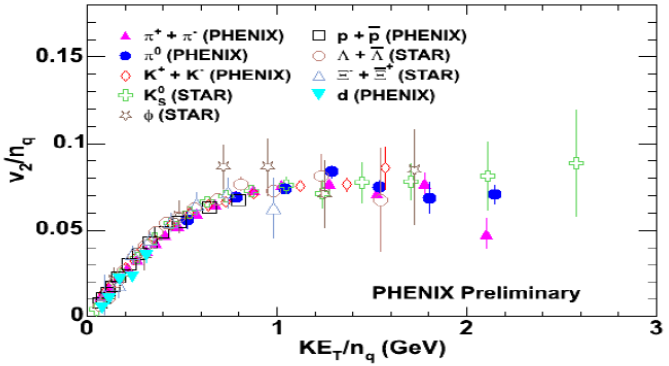
Scientific Mission:

- Study hot, dense Nuclear Matter
  - Search for Quark-Gluon Plasma
- Study gluon content of proton
  - Origin of the spin of the proton using polarized proton beams

Evidence at RHIC for a Strongly Interacting Quark-Gluon Plasma - "sQGP"

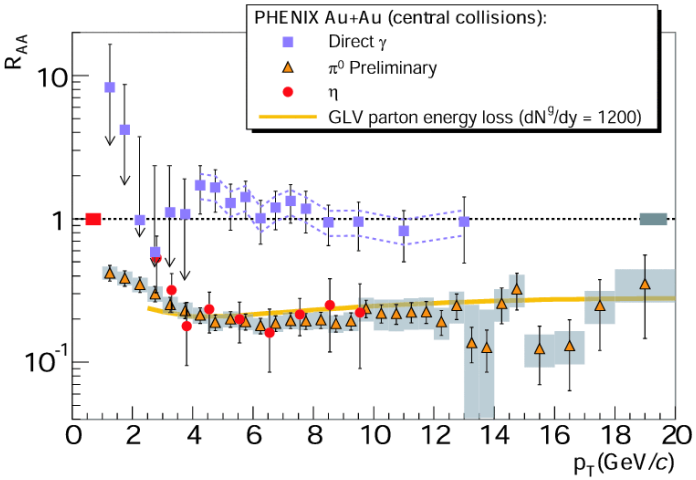
Good agreement of hydro computations with radial and elliptic flow data





Quark Coalescence models reproduce elliptic flow data

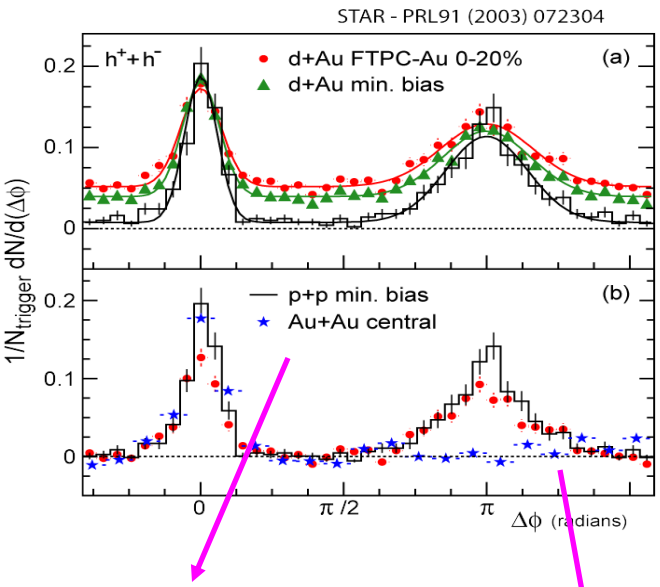
Very large energy loss of jets

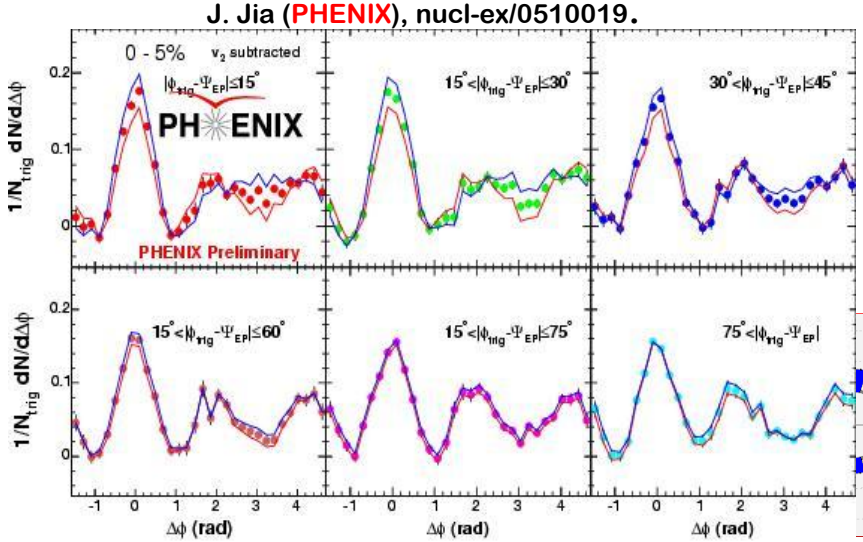


The evidence is strong that one has made a system of strongly interacting quarks and gluons – sQGP

Many unknowns, e.g. viscosity effects - computation is a theoretical challenge

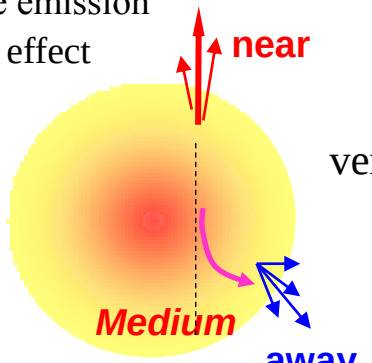
Jet Suppression Studies at RHIC



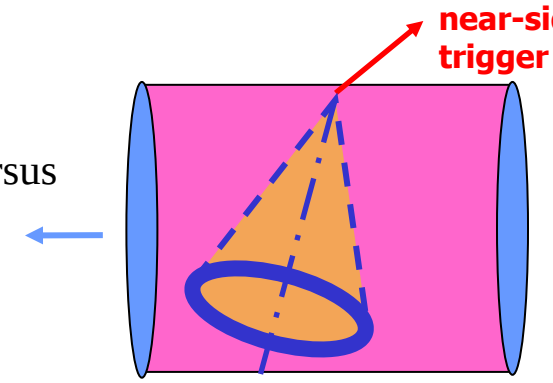


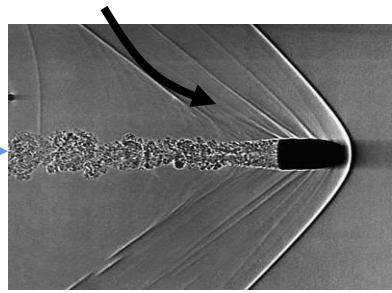
- Near-side jet unchanged
- Away-side nearly disappeared - consistent with "surface emission"
- d+Au ~ p+p: final state effect

Hint of stronger double-peak structure out-of-plane than in-plane Mach Cones in Plasma?



versus





Nuclear Physics at the LHC

In 2002, the Nuclear Science Advisory Committee Long Range Plan provided an outlook on new domains of science to be explored, that included the LHC:

> **"It would be wise to make a modest investment… so that some U.S. participation is possible. This program should focus on those aspects of relativistic heavy ions not easily addressed at RHIC".**

In 2004, the NSAC subcommittee reviewed the U.S. Program in Heavy-Ion Physics, noting "the LHC will open up a new regime in relativistic heavy-ion physics with significant opportunities for discoveries" and recommended that:

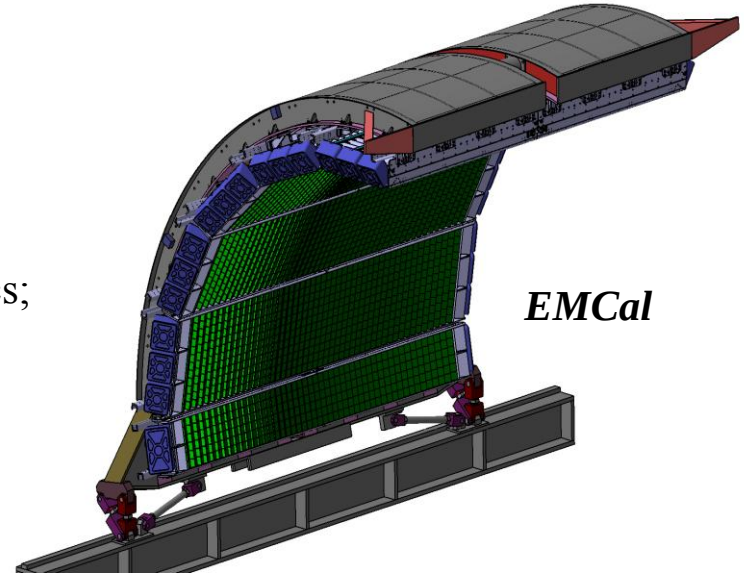
- Participation at the LHC should become a new component of the U.S. Heavy Ion program;
- This participation should receive comparable investment priority with each of the two near-term upgrade programs for the large RHIC detectors.

The science of high energy density physics (HEDP) was also highlighted in the NRC report *Connecting Quarks with the Cosmos*, and the interagency response to this report, which identified HEDP as the most effective way to address one of the eleven compelling science questions: **What Are the New States of Matter at Exceedingly High Density and Temperature?**

An Electromagnetic Calorimeter for ALICE – A Large Ion Collider Experiment

ALICE/EMCal
DOE TPC: $13.5 Million
FY 2007-FY 2011
CD-2/3 in February 2008

- LHC - world's highest energy facility for particle physics; heavy ion studies @ ~4 wks/yr
- Electromagnetic calorimeter (EMCal) for the ALICE experiment is a major investment for Nuclear Physics
- Joint U.S., French, and Italian project

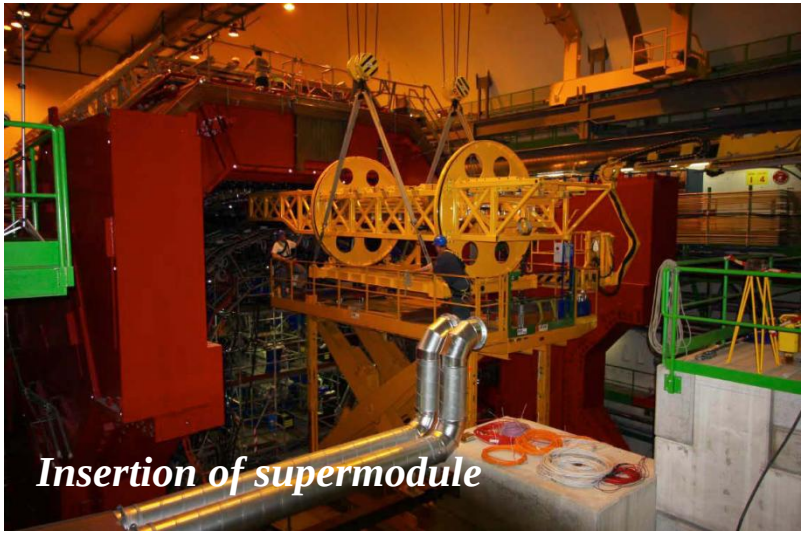


EMCal

Project Deliverables:

- Seven EMCal supermodules
- Three are contributed by European collaborators

- **Status:**
- All EMCal supermodules are fabricated
- Four supermodules are installed for the present run



Insertion of supermodule

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Research with the EMCal and ALICE

Scientific Research with the ALICE EMCal

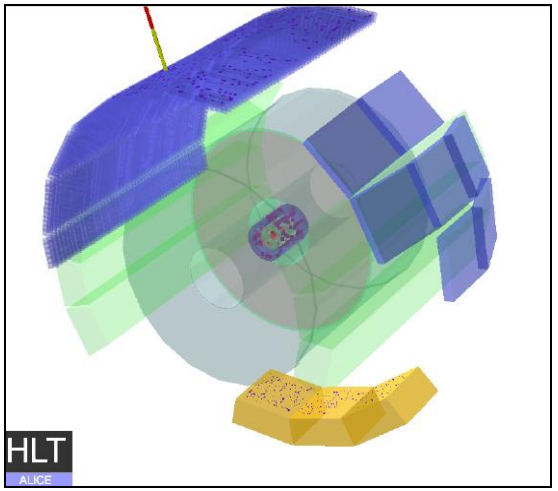
- Triggering on high p_T π_0, gammas and electrons to study jet quenching through leading particles
- Hard processes modified by the nuclear medium
- Jet correlations and jet reconstruction

ALICE-USA Research Collaboration

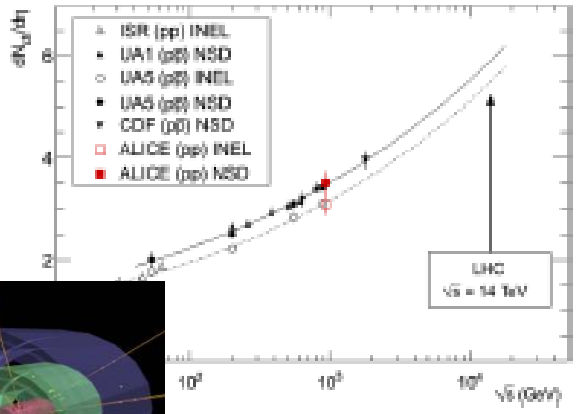
- Seven Universities and three National Laboratories
- About 34 PhD scientists

Computing for ALICE

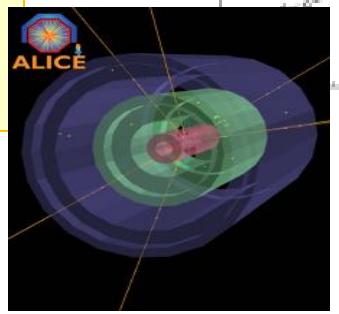
- NERSC/PDSF at LBNL; cluster at LLNL



ALICE Event from first LHC Beams



First proton--proton collisions at the LHC as observed with the ALICE detector: measurement of the charged particle pseudo-rapidity density at 900 GeV. Euro. Phys. Jour. C 65, 111 (Jan 2010).



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Di-jet Calorimeter (DCal)
Extension to the EMCal

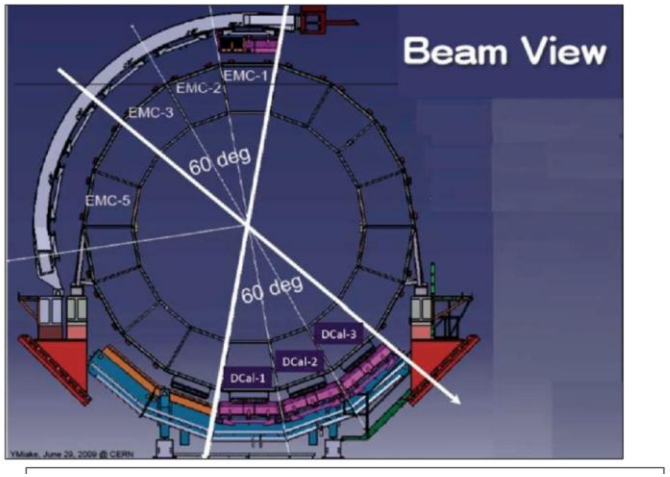
ALICE Di-Jet Calorimeter (DCal)

- Extends acceptance of the EMCal
- Enables hadron-jet and di-jet correlations

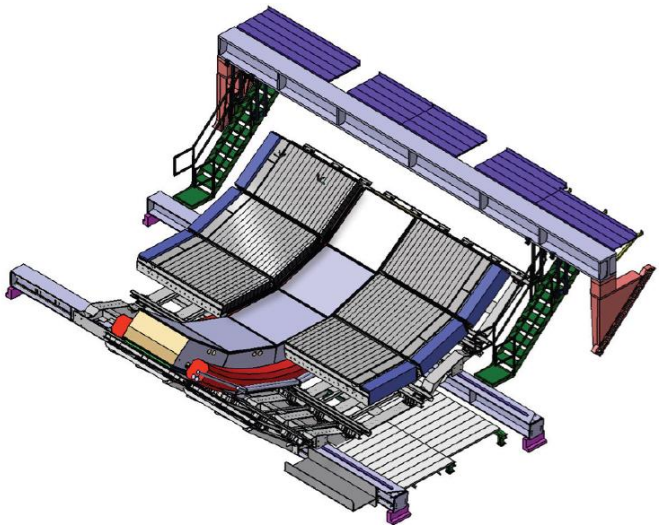
- Builds on EMCal technology

- Six supermodules with reduced length are planned
- US contributes three supermodules
- Together EMCal and DCal form a two-arm spectrometer

- DCal Collaboration
  - France, Italy, US, China, and Japan



DCal Concept



The Compact Muon Solenoid (CMS) Experiment

Heavy Ion Research with the Compact Muon Solenoid

- Initial conditions in heavy-ion collisions--the role of the color glass condensate (CGC)
- Properties of the near-ideal liquid produced in heavy-ion collisions and its evolution from the initial conditions
- Mechanism of jet quenching using highly differential probes

NP Investment in High Level Trigger Computing

Collaboration

- MIT is the lead institution
- Six Universities and one National Laboratory
- About 20 PhDs

Computing

- Tier-2 computing center at Vanderbilt University
- Simulation cluster at MIT

Long-Range Near-Side Angular Correlations in Proton-Proton Interactions in CMS

The CMS Collaboration Results on two-particle angular correlations for charged particles emitted in proton-proton collisions at center of mass energies of 0.9, 2.36 and 7TeV over a broad range of pseudorapidity (η) and azimuthal angle (φ) are presented using data collected with the CMS detector at the LHC. Short-range correlations in Δη, which are studied in minimum bias events, are characterized using a simple independent cluster parameterization in order to quantify their strength (cluster size) and their extent in η (cluster decay width). Long-range azimuthal correlations are studied more differentially as a function of charged particle multiplicity and particle transverse momentum using a 980nb−1 data set at 7TeV. In high multiplicity events, a pronounced structure emerges in the two-dimensional correlation function for particles in intermediate pT's of 1-3GeV/c, $2.0 < |\Delta\eta| < 4.8$ and $\Delta\varphi \approx 0$. This is the first observation of such a ridge-like feature in two-particle correlation functions in pp or p-pbar collisions.