Geant4 Simulations of the Zero Degree Calorimeter Reaction Plane Detector

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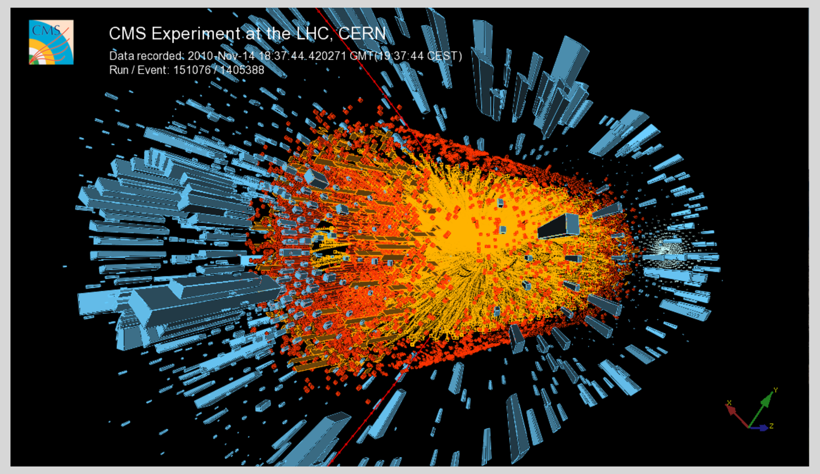
Heavy-Ion Collisions

- Microseconds after the Big Bang, under extreme temperature and pressure, a phase of matter existed consisting of free quarks and gluons, called the quark-gluon plasma (QGP)
- These conditions are recreated in a lab using heavy-ion collisions to create a sufficiently high energy system that melts nuclear matter to form a deconfined state



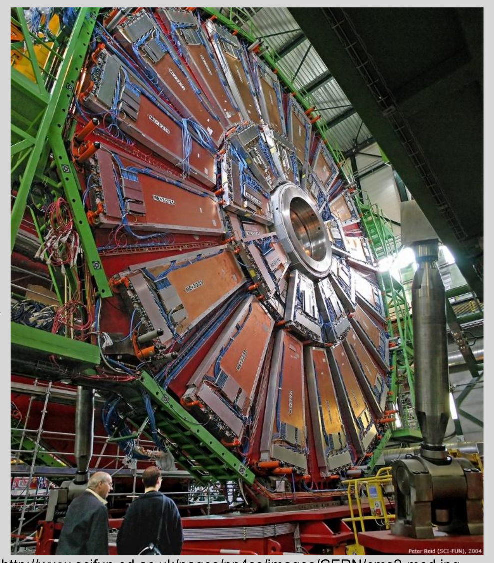
http://nuclear.ucdavis.edu/img/hiUpsilon1.png

The Large Hadron Collider

The Large Hadron Collider (LHC), located outside of Geneva, is the world's largest and highest energy particle collider. Protons and lead nuclei are accelerated to ultra-relativistic velocities along two 27 km circular underground tubes.

http://www.greatdreams.com/hadron/HadronCollider_6.jpg

The beams intersect at four locations. Housed at one is the Compact Muon Solenoid (CMS), a 15 meter diameter detector that serves as the basis of a collaboration of nearly 4,000 people and 200 institutions across more than 40 countries.



http://www.scifun.ed.ac.uk/pages/pp4ss/images/CERN/cms2-med.jpg

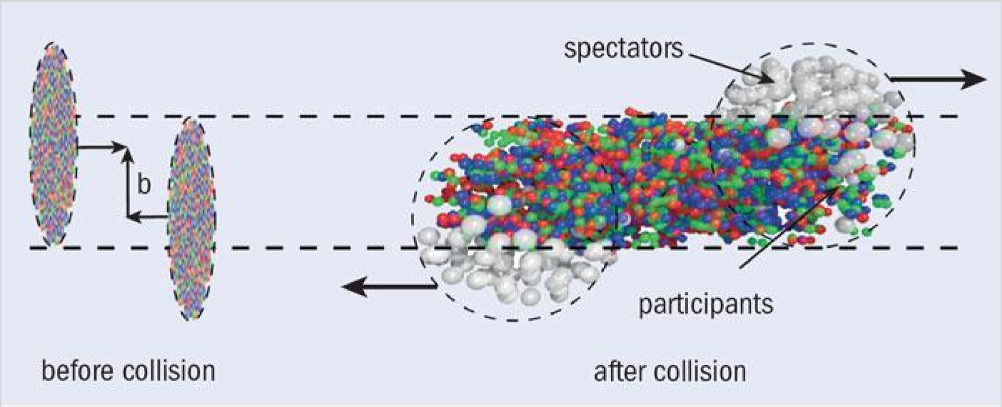
The Zero Degree Calorimeter

- Located 140 meters down the beam pipe from CMS are the Zero Degree Calorimeters (ZDCs), which are used to detect neutral particles such as photons and neutrons
- Our proposed upgrade will give the ZDCs the ability to accurately measure the two most important collision characteristics, the reaction plane and the centrality

Centrality

In order to characterize the collision event, both the centrality and the reaction plane of the event must be known in order to determine the quantity of participating particles, and their initial states.

- When two particles collide, the degree of overlap between them, the centrality, determines the nature of the collision
- The measure of the percentage of collisions with overlap below a given value is used to calculate centrality, with values close to 0% centrality indicating nearly a full overlap.
- Nucleons not directly involved in the collision are called spectators and continue down the beam pipes

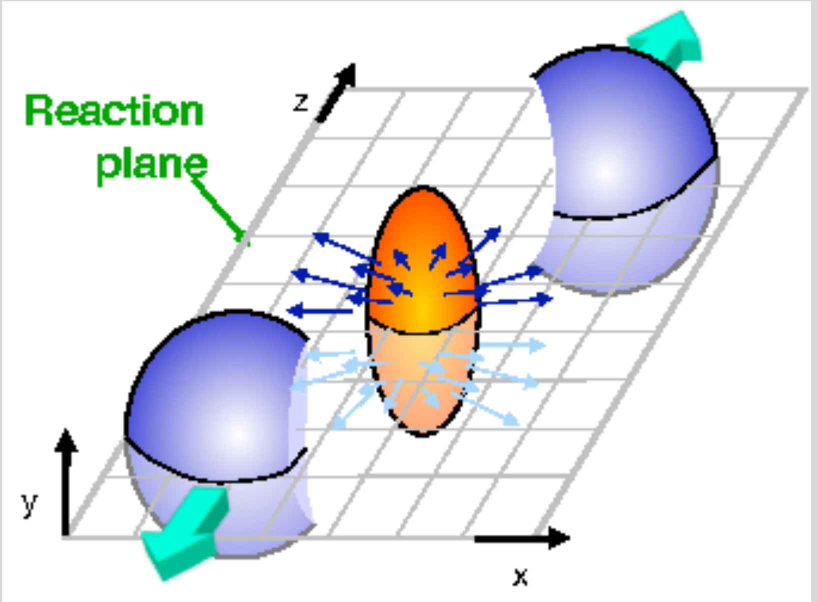


http://images.iop.org/objects/ccr/cern/thumb/53/4/18/CCfir5_04_13.jpg

The Reaction Plane

The plane bisecting two colliding neutrons, the reaction plane, can be measured by the distribution of spectator neutrons along the azimuthal angle to the beam.

- The upgrade adds a 4x4 quartz array, called the Spectator Reaction Plane Detector (RPD) that will measure the distribution of spectator neutrons
- The new proposed quartz array will allow both centrality and reaction plane to be measured for ultra-relativistic nucleus collisions.
- This will facilitate the analysis of the correlations that exist between all particles involved in the collisions

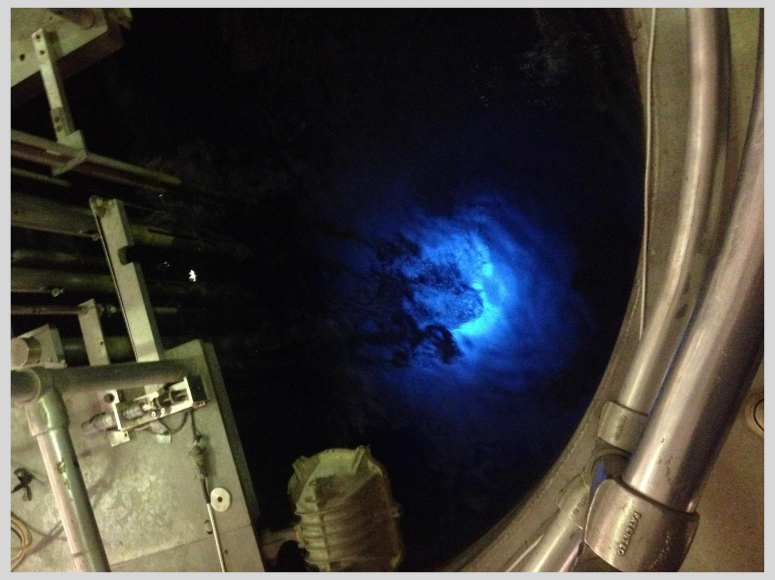


https://inspirehep.net/record/1256115/files/figs_figure3a.png

Cherenkov Radiation

When charged particles enter a volume at velocities higher than the speed of light in that volume, they undergo deceleration through the emission of visible light.

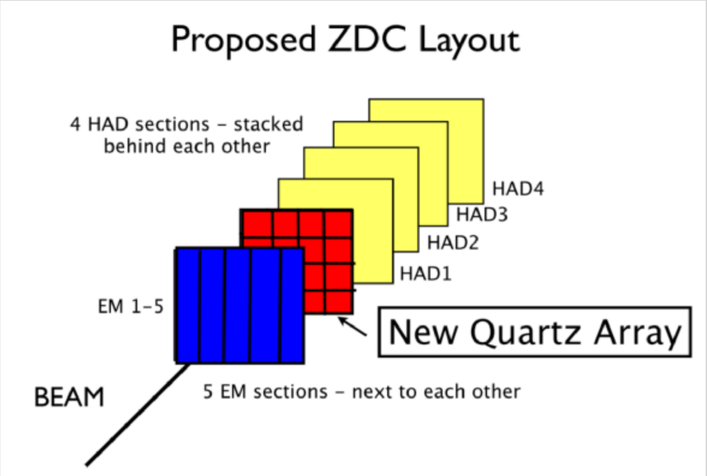
- This occurs when particles are traveling faster than the phase velocity of light in the medium ***v = c/n*** (**n** is the refractive coefficient of the medium and **c** is the speed of light in a vacuum)
- The ratio of ***β = v/c*** for an electron entering quartz is set equal to ***1/n*** to calculate the threshold for producing Cherenkov radiation: when ***β > 1/n*** Cherenkov photons are produced
- The distribution of Cherenkov photons may be measured and used to calculate the relative number and orientation of the secondary particle shower incident from the EM section



Cherenkov Light visible from the Research Reactor at the University of Maryland, College Park

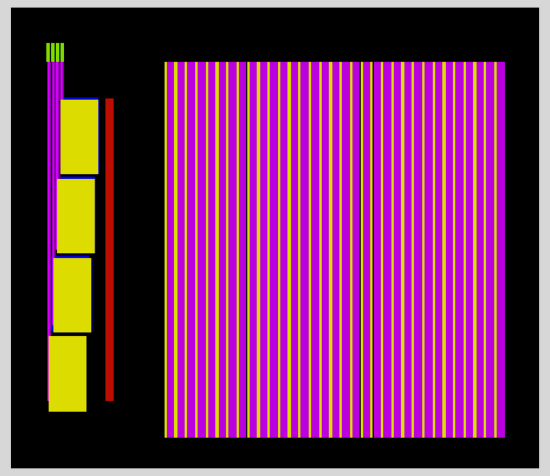
RPD Detector Construction

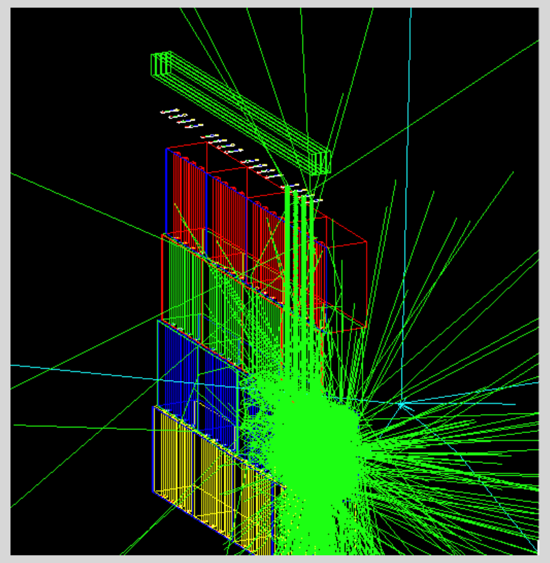
- The incoming spectator neutrons pass through a section of alternating layers of lead and tungsten, called the Electromagnetic (EM) section, where secondary particles are produced
- The secondary particle shower hits the quartz RPD array and produces Cherenkov radiation
- Photons from the Cherenkov radiation are transported through wavelength-shifting fibers and coupled to photomultiplier tubes (PMTs)



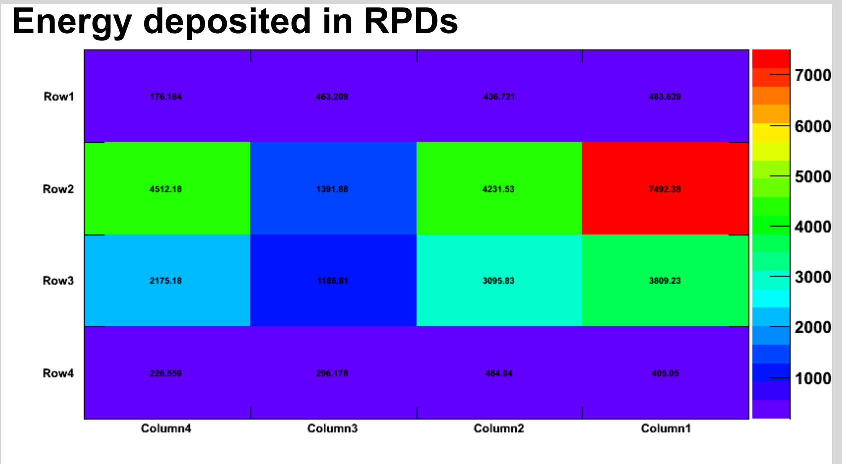
RPD Simulations

Integral to the upgrade is the full understanding of the expected detector response, which is achieved through simulations using Geant4. A simulated version of the ZDC is built to include the EM (alternating purple and yellow boxes in left image), a structural copper panel (red), the RPD array (yellow), WLSs (purple), and PMTs (green).





By comparing the user defined initial neutron distribution and the simulated detector response, the detector may be verified to work as expected.



The readout from the PMTs is displayed in a 2D histogram. The reaction plane is determined by applying the following set of equations to the data:

$$\phi[i][j] = \sum_{i=1}^{4}\sum_{j=1}^{4} tan^{-1}\left(\frac{Y_{P_{ij}}}{X_{P_{ij}}}\right)$$

$$\vec{x} = \sum_{i=1}^{4}\sum_{j=1}^{4} E_{ij}cos(n\phi_{ij})$$

$$\vec{y} = \sum_{i=1}^{4}\sum_{j=1}^{4} E_{ij}sin(n\phi_{ij})$$

$$\Psi_n = \frac{1}{n}tan^{-1}\frac{\vec{y}}{\vec{x}}$$

Summary and Future Work

- Reaction Plane and Centralities are important components of Heavy Ion Collisions
- Geant4 simulations are essential to testing of the RPD and calibration of data
- Preliminary findings show detector behaves as expected, with more advanced tests planned