News

COSMIC RAYS

IceCube observations challenge ideas on cosmic-ray origins

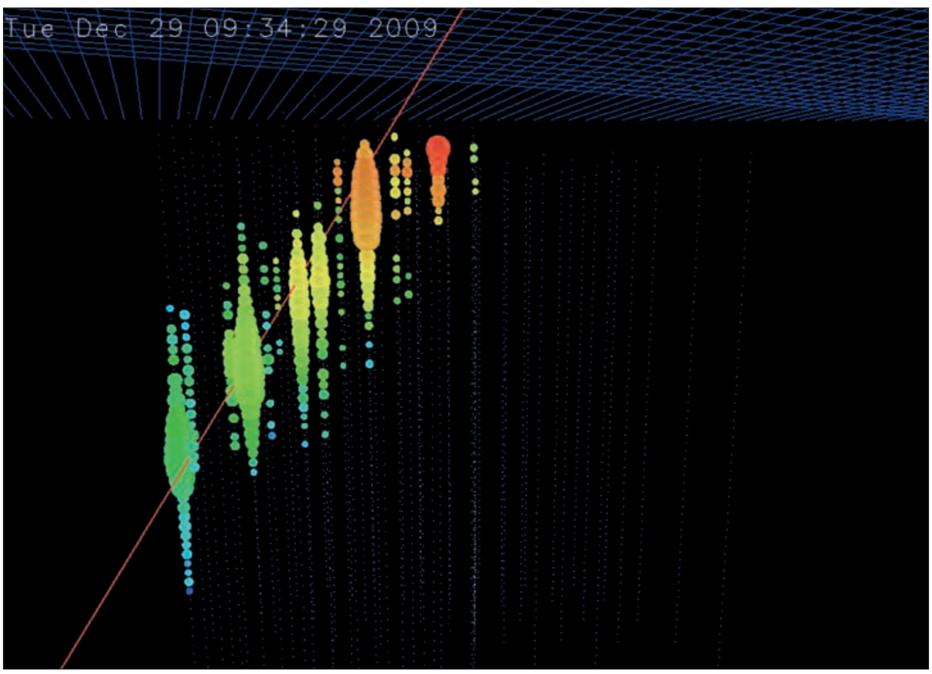
The IceCube collaboration, with a detector that looks at a cubic kilometre of ice at the South Pole, has searched for evidence of neutrinos associated with gamma-ray bursts (GRBs). They find none at a level 3.7 times lower than models predict, indicating that cosmic rays with energies above 10^8 TeV originate from some other source.

Where nature accelerates particles to 10^8 TeV has been one of the long-standing questions of extreme astrophysics. Although the flux of the highest-energy cosmic rays arriving at Earth is small, it pervades the universe and corresponds to a large amount of energy. Equally mysterious in origin, gamma-ray bursts (GRBs), some associated with the collapse of massive stars to black holes, have released a small fraction of a solar mass of radiation more than once a day since the Big Bang. The assumption is that they invest a similar amount of energy in the acceleration of protons, which explains the observed cosmic-ray flux. This leads to the 15-year-old prediction that when protons and gamma rays co-exist in the GRB fireball they photoproduce pions that decay into neutrinos. The prediction is quantitative (albeit with astrophysical ambiguities) because astronomers can calculate the number of photons in the fireball, and the observed cosmic-ray flux dictates the number of protons. Textbook particle physics then predicts the number of neutrinos.

With 5160 photomultiplier tubes, the IceCube experiment has transformed a cubic kilometre of Antarctic ice into a Cherenkov detector (*CERN Courier* March 2011 p28). Even while still incomplete, the instrument reached the sensitivity to observe GRBs, taking data with 40 and 59 of the final number of 86 photomultiplier strings. The measurement is relatively easy because it exploits alerts from the NASA's Swift satellite and Fermi Gamma-Ray Space Telescope to look for neutrinos arriving from the right direction at the right time. The window is small enough to do a background-free measurement because accidental coincidence with a high-energy atmospheric neutrino is negligible.

During the periods of data-taking, some 307 GRBs had the potential to result in neutrinos that IceCube could detect. However, the experiment found no evidence for any neutrinos that could be associated with the GRBs. This implies either that GRBs are not the only sources of cosmic rays with energies exceeding 10^8 TeV or that the efficiency of neutrino production is much lower than has been predicted.

With GRBs on probation, the stock rises for the alternative speculation that associates supermassive black holes at the centres of galaxies with the enigmatic cosmic accelerators.



An IceCube event within 0.2° of the direction of a gamma-ray burst (GRB) observed by the Swift satellite. The reconstruction yields an energy of 109 TeV and an angular error of 0.2°. Although it misses the time of the GRB by 14 hours, the background is so low that this was the most significant candidate.

Further reading

IceCube collaboration 2012 *Nature* **484** 351.

Sommaire en français

LHC PHYSICS

CMS discovers the Ξ_b^{*0}

The CMS experiment has discovered its first new particle. The new state is observed with a significance exceeding 5 σ and a mass of 5945.0 ± 2.8 MeV. This mass and the observed decay mode are consistent with its being the beauty-strange baryon known as Ξ_b^{*0}.

Understanding the detailed spectroscopy of the various families of hadrons has been a quest of scientists ever since quarks were recognized as being the building blocks of protons, neutrons and other hadrons. Baryons are composed of three quarks and if they contain a beauty (b) quark and a strange (s) quark then they are members of the Ξ_b family. Depending on whether the third valence quark is a u or a d, the resulting baryon is either the neutral Ξ_b^0 or the charged Ξ_b^-. While the charged and neutral lowest-mass states were already known, none of the heavier states had so far been seen. The newly discovered particle is probably the Ξ_b^{*0}, with a total angular momentum and parity, $J^P = 3/2^+$. Its observation helps in understanding how quarks bind and in further validating the theory of strong interactions.

The observation was made in a data sample of 5.3 fb^{-1} proton–proton collisions at a centre-of-mass energy of 7 TeV, delivered by the LHC in 2011. Figure 1 shows a typical event, where a candidate Ξ_b^{*0} (also appropriately called the "cascade b baryon") leads to a cascade of decays, $\Xi_b^{*0} \to \Xi_b^-\pi^+$, $\Xi_b^- \to J/\Psi\Xi^-$, $J/\Psi \to \mu^+\mu^-$, $\Xi^- \to \Lambda^0\pi^-$ and $\Lambda^0 \to p\pi^-$, ending in one proton, two muons, and three pions. The existence of the Ξ_b^{*0} is established by detecting all of these particles and measuring the charge, momentum and point of origin (the vertex) for each one. Requiring that the secondary decay vertices be displaced from the primary vertex reduces the background caused by random combinations of uncorrelated particles, which are copiously produced in high-energy proton–proton collisions.

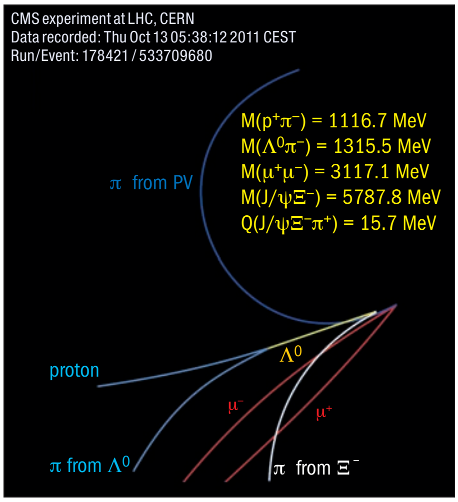


Fig. 1. Display of a typical event, showing the reconstructed decay products of the newly discovered particle.

The invariant-mass distribution of the $J/\Psi\Xi^-$ pairs shows a clear peak corresponding to the Ξ_b^- signal, with a mass in good agreement with the world average. The Ξ_b^{*0} is expected to decay promptly to $\Xi_b^-\pi^+$ pairs, so candidates were sought by combining the reconstructed Ξ_b^- with a track (assumed to be a pion) coming from the primary vertex. To cancel measurement errors partially and so increase the sensitivity, the analysis looked at the mass difference $Q = M(J/\Psi\Xi^-\pi^+) - M(J/\Psi\Xi^-) - M(\pi)$. Figure 2 shows the mass difference for 21 events in the range $12 < Q < 18$ MeV, which clearly exceed the 3.0 ± 1.4 events expected in the absence of a new particle.

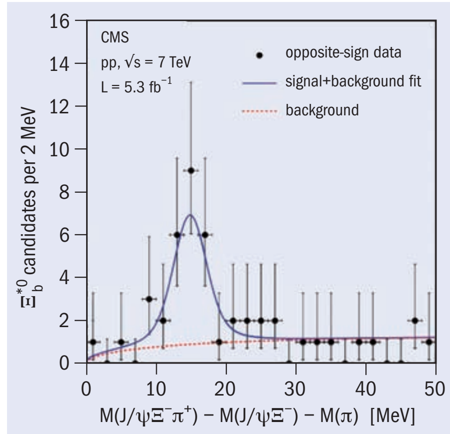


Fig. 2. Mass-difference distribution, revealing the new beauty (b) baryon.

The detection of this new particle was possible thanks only to the excellent tracking and vertexing capabilities of the CMS experiment, combined with high-purity dimuon triggers that identify decays of the J/Ψ meson "on the fly", before storing the events. This measurement shows that CMS can unravel complicated chains of particle decays and bodes well for future discoveries of rare particles.

Further reading

CMS collaboration 2012 arXiv:1204.5955v1 [hep-ex].

Dijets confirm the Standard Model

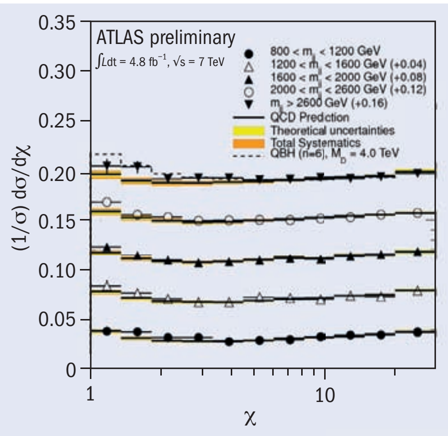
Dijet measurements provide an excellent tool not only to probe high transverse-momentum parton interactions to study QCD but also to look for signs of new phenomena beyond the Standard Model. Thanks to the outstanding performance of the LHC in 2011, the ATLAS experiment recorded nearly 30,000 events with dijet masses above 2 TeV and even observed dijet masses up to 4.6 TeV.

The collaboration has used the full 2011 data sample – corresponding to nearly 5 fb^{-1} of integrated luminosity – for a measurement of the dijet cross-section as a function of mass and rapidity difference. The data were first corrected for detector effects – paying particular care to the effect of possible multiple interactions per beam crossing – and the measured cross-sections were then compared with various predictions of QCD. While there are small deviations in some models at the higher end of the spectrum, overall the agreement with QCD is reasonably good.

QCD predicts that the cross-section falls steeply with dijet mass. New, as yet unobserved, particles would typically give rise to resonances or bumps on top of this smoothly falling spectrum. ATLAS observes no bumps, allowing limits to be set on a number of theories that predict such particles.

Angular distributions can also be used to search for deviations from the Standard Model. They are typically measured in bins of dijet mass, where the scattering angle is transformed into a variable known as χ (see figure). The Standard Model predicts that these distributions should be relatively flat, while many theories beyond the Standard Model predict a rise at low values of χ.

The measured distributions are found to be in agreement with QCD predictions, allowing limits to be set on various models for new physics. For one of these models, where quarks are no longer fundamental particles but are instead composite objects, this analysis sets a limit on the compositeness scale – the scale of the constituent binding energies – at 7.8 TeV.



Dijet angular distributions as a function of $\chi = exp(|y_1 - y_2|)$ in five bins of dijet mass show no sign of new physics.

LHC NEWS

Ramping up to higher luminosity

After a flying start, with the first stable beams at the new energy of 4 TeV on 5 April, the LHC successfully operated with 1380 bunches per beam – the maximum planned for 2012 – on 18 April. In the days that followed, the machine reached a record peak luminosity of about 5.6×10^{33} cm^{-2}s^{-1}, with a bunch intensity of 1.4×10^{11} protons per bunch and a new highest stored energy of 120 MJ per beam.

As it entered a two-day machine-development period on 21–22 April, almost 1 fb^{-1} of data had been delivered to the experiments, a feat that took until June in 2011. The machine development focused on topics relevant for the 2012 physics-beam operation and was followed by a five-day technical stop, the first of the year.

The restart from 27 April onwards was slowed down by several technical faults that led to low machine availability and the ramp back up in intensity took longer than initially planned. LHC operation was further hampered by higher than usual beam losses in the ramp and squeeze. These required time to investigate the causes and to implement mitigation measures.

On 10 May the machine began running again with 1380 bunches and a couple of days later saw one of the year's best fills, lasting for 13 hours and delivering an integrated luminosity of 120 pb^{-1} to ATLAS and CMS. By 15 May, after careful optimization of the beams in the injectors, the luminosity was back up to pre-technical-stop levels. The aim now is for steady running accompanied by a gentle increase in bunch intensity in order to deliver a sizeable amount of data in time for the summer conferences.

Deferred triggering optimizes CPU use

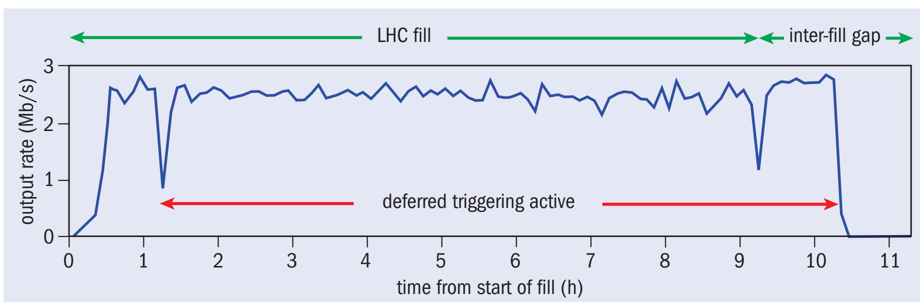
Like all of the LHC experiments, LHCb relies on a tremendous amount of CPU power to select interesting events out of the many millions that the LHC produces every second. Indeed, a large part of the ingenuity of the LHCb collaboration goes into developing trigger algorithms that can sift out the interesting physics from a sea of background. The cleverer the algorithms, the better the physics, but often the computational cost is also higher. About 1500 powerful computing servers in an event filter farm are kept 100% busy when LHCb is taking data and still more could be used.

However, this enormous computing power is used less than 20% of the time when averaged over the entire year. This is partly because of the annual shutdown, so preparations are under way to use the power of the filter farm during that period for offline processing of data – the issues to be addressed include feeding the farm with events from external storage. The rest of the idle time is a result of the gaps between the periods when there are protons colliding in the LHC (the "fills"), which typically last between two and three hours, where no collisions take place and therefore no computing power is required.

This raises the question about whether it is somehow possible to borrow the CPU power of the idle servers and use it during physics runs for an extra boost. Such thoughts led to the idea of "deferred triggering": storing events that cannot be processed online on the local disks of the servers, and later, when the fill is over, processing them on the now idle servers.

The LHCb Online and Trigger teams quickly worked out the technical details and started the implementation of a deferred trigger early this year. As often happens in online computing, the storing and moving of the data is the easy part, while the true challenge lies in the monitoring and control of the processing, robust error-recovery and careful bookkeeping. After a few weeks, all of the essential pieces were ready for the first successful tests using real data.

Depending on the ratio of the fill length to inter-fill time, up to 20% of CPU time can be deferred – limited only by the available disk space (currently around 200 TB) and the time between fills in the LHC. Buying that amount of CPU power would correspond to an investment of hundreds of thousands of Swiss francs. Instead, this enterprising idea has allowed an increase in the performance of its trigger, allowing time for more complex algorithms (such as the online reconstruction of K_S decays) to extend the physics reach of the experiment.



Measured output rate to permanent storage of one of the LHCb servers during and after an LHC fill. The output rate increases by a few per cent after the end of a fill – because of the reduced network traffic – while the remaining, locally stored events are processed.

NEUTRINOS

RENO observes disappearance of electron-antineutrinos

The Reactor Experiment for Neutrino Oscillations (RENO) has performed a definitive measurement of the neutrino-oscillation mixing angle, θ_{13}, by observing the disappearance of electron-antineutrinos emitted from a nuclear reactor, with a significance of 4.9 σ

RENO detects antineutrinos from six reactors, each with a thermal power output of 2.8 GW_{th}, at Yonggwang Nuclear Power Plant in Korea. The reactors are almost equally spaced in a line about 1.3 km long and the experiment uses two identical detectors located at 294 m and 1383 m on either side of the centre of this line, beneath hills that provide, respectively, 120 and 450 m of water-equivalent of rock overburden to reduce the cosmic backgrounds. This symmetric arrangement of reactors and detectors is useful for minimizing the complexity of the measurement. RENO is the first experiment to measure θ_{13}, the smallest neutrino-mixing angle and the last to be known, with two identical detectors.

In the 229-day data-taking period from 11 August 2011 to 26 March 2012, the far (near) detector observed 17,102 (154,088) electron-antineutrino candidate events with a background fraction of 5.5% (2.7%). During this period, all six reactors were operating mainly at full power, with two reactors being off for a month each for fuel replacement.

The two identical antineutrino detectors allow a relative measurement through a comparison of the observed neutrino rates. Measuring the far-to-near ratio of the reactor neutrinos in this way can considerably reduce several systematic errors. The relative measurement is independent of correlated uncertainties and helps in minimizing uncorrelated reactor uncertainties.

Each detector comprises four layers. At the core lies the target volume of 16.5 tonnes of liquid scintillator that is doped with gadolinium. An electron-antineutrino can interact with a free proton in the scintillator, $\bar{\nu} + p \rightarrow e^+ + n$. The positron from this inverse β-decay annihilates immediately giving a prompt signal. The neutron wanders into the target volume, eventually being captured by the gadolinium – giving a delayed signal. The delayed coincidence between the positron and neutron signals provides the distinctive signature of inverse β-decay.

The central target volume is surrounded by a 60 cm layer of liquid scintillator without gadolinium, which serves to catch γ-rays escaping from the target volume, thus increasing the detection efficiency. Outside this γ-catcher, a 70 cm buffer-layer of mineral oil shields the inner detectors from radioactivity in the surrounding rocks and in the 354 photomultiplier tubes (10-inch) that are installed on the inner wall of the buffer container. The outermost veto layer consists of 1.5 m of pure water, which serves to identify events coming from the outside through their Cherenkov radiation and to shield against ambient γ-rays and neutrons from the surrounding rocks. Both detectors are calibrated using radioactive sources and cosmic-ray induced background samples.

Based on the number of events at the near detector and assuming no oscillation, RENO finds a clear deficit, with a far-to-near ratio $R = 0.920 \pm 0.009$ (stat.) ± 0.014 (syst.). The value of $\sin^2 2\theta_{13}$ is determined from a χ^2 fit with pull terms on the uncorrelated systematic uncertainties. The number of events in each detector after the background subtraction has been compared with the expected number of events, based on the neutrino flux, detection efficiency, neutrino oscillations and contribution from the reactors to each detector determined by the baselines and reactor fluxes. The best-fit value obtained is $\sin^2 2\theta_{13} = 0.113 \pm 0.013$ (stat.) ± 0.019 (syst.), which excludes the no-oscillation hypothesis at 4.9 σ.

The RENO collaboration consists of about 35 researchers from Seoul National University, Chonbuk National University, Chonnam National University, Chung Ang University, Dongshin University, Gyeongsang National University, Kyungpook National University, Pusan National University, Sejong University, Seokyeong University, Seoyeong University and Sungkyunkwan University.

Further reading

J K Ahn *et al.* RENO collaboration 2012 *Phys. Rev. Lett.* **108** 191802.

CERN

Hungary to host extension to CERN data centre

Following a competitive call for tender, CERN has signed a contract with the Wigner Research Centre for Physics in Budapest for an extension to CERN's data centre. Under the new agreement, the Wigner Centre will host CERN equipment that will substantially extend the capabilities of Tier-0 of the Worldwide LHC Computing Grid (WLCG) and provide the opportunity to implement solutions for business continuity. The contract is initially until 31 December 2015, with the possibility of up to four one-year extensions thereafter.

The WLCG is a global system organized in tiers, with the central hub being Tier-0 at CERN. Eleven major Tier-1 centres around the world are linked to CERN via dedicated high-bandwidth links. Smaller Tier-2 and Tier-3 centres linked via the internet bring the total number of computer centres involved to more than 140 in 35 countries. The WLCG serves a community of some 8000 scientists working on LHC experiments, allowing seamless access, distributed computing and data-storage facilities.

The Tier-0 at CERN currently provides some 30 PB of data storage on disk and includes the majority of the 65,000 processing cores in the CERN Computer Centre. Under the new agreement, the Wigner Research Centre will extend this capacity with 20,000 cores and 5.5 PB of disk storage, and will see this doubling after three years.

Artist's impression of the new data centre. (Image credit: Wigner Research Centre.)

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