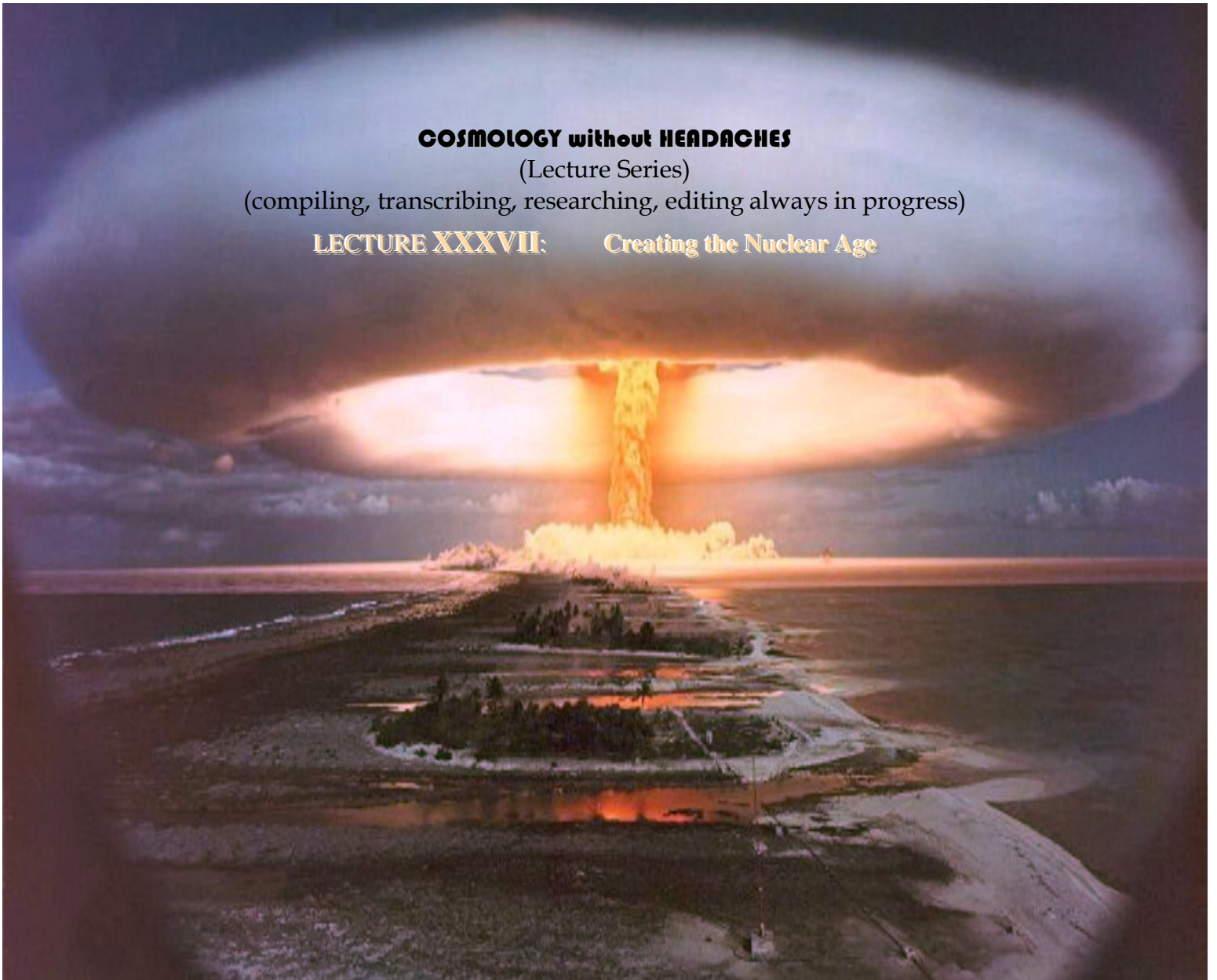


COSMOLOGY without HEADACHES

(Lecture Series)

(compiling, transcribing, researching, editing always in progress)

LECTURE XXXVII: Creating the Nuclear Age

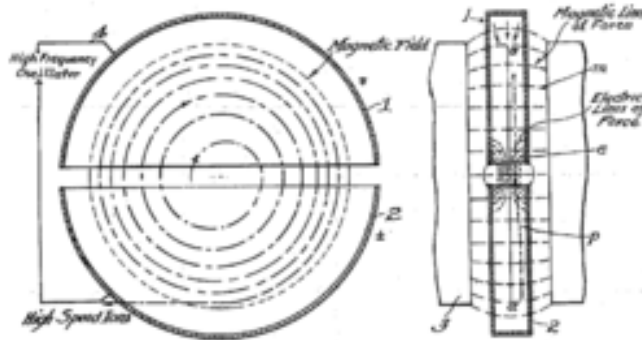


Einstein continued working on the general theory of relativity, his self-assigned life-time task. He had explained gravity in a radically new way, which seemed to have eliminated the problem of force at a distance, yet he could not break free of what he considered the most obvious fact—a *necessary* fact of physics (if ‘physics’ is to retain any meaning at all): that there is something real, something physical; that at the bottom of our scientific investigations we will find substance. Surely it was just a matter of determining the right way of seeing and understanding. Thus he could not abide the growing notion in quantum physics that material solidity was illusory: a mental state of the observer. He abhorred the position of Bohr and his disciples: that the quantum world has no foundation, or that the underlying principle of the universe was sheer probability, or that quanta had both a wave and a particle nature. He complained, despite its mounting record of prediction and its growth in acceptability among new physicists, that quantum mechanics was incomplete. A proper theory might well be complicated, difficult to digest, and mathematically esoteric but it could not contain such paradoxes as wave-particle duality and the principle of uncertainty. It just had to make more sense; i.e., theories could not be illogical or self-contradictory.

So, reluctantly, the anti-classicists departed, leaving their beloved champion in a cloud of their quantum dust as they propelled themselves into the uncertain future of what, at least at moments of introspection, they must have realized was no longer physics. Maybe the original, 17th century term was more accurate than they knew: *natural philosophy*. Perhaps it could have been called ‘transphysics’ or ‘superphysics’. But that would have been much too close to *metaphysics*. We do hear references today to *subatomic* physics and even ‘*subparticle* physics’, which means pretty much the same thing as ‘*sub-physics*’. By including the words ‘atom’ and ‘particle’, this nomenclature tends falsely to preserve something of the classical notion of action and reaction: ever tinier versions of clashing causality—pretty much what Einstein hoped they would ultimately find. But it is not what they found at all.

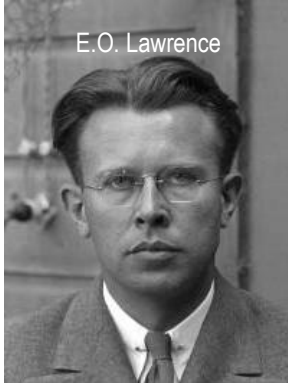
The early quantists themselves, at first, were nonplused over where logic and their best mathematical reasoning seemed to be leading them. They struggled, they hesitated, they conferred, they resisted belief, they reasoned and calculated and predicted what seemed crazy by every classical notion, only to see experimental results verify, again and again, what they had hoped and yet feared would be true: The design of the world at its most fundamental level appeared to be nothing but forces and fields and waves, the character of which were altered by the very act of observation such that no conclusions could be reached regarding their true nature—if they had a nature, a state of being, some simple attribute that could be identified as their essence. Yet, mathematically, these ‘events’ could be assumed to have a particle alter-ego that made it possible to ‘know’ or ‘suppose’ and thus ‘measure’ (read: ‘calculate’) sizes and speeds and masses and directions: attributes or ‘states’ of phenomena so tiny and quick they could hardly be imagined, let alone directly observed. And yet it was believed these theoretical ‘thingamabobs’ might be captured and manipulated into violent collisions and reduced to traces of debris; traces that would ‘reveal’ (or a better word might be ‘suggest’) even more mysterious stuff at an even more minute level of almost-reality.

To carry on such work, the first cyclotron was built by its inventor, **Ernest O. Lawrence** [1901-1958], at UC Berkeley in 1929. I want to say there was barely even a department of physics, then, at the University of California. Whatever physics was being taught certainly had nothing to do with today’s high energy experiments. Experimenters at that time, in most cases, were still building their own gizmos to test hypotheses. Lawrence built his first cyclotron for an estimated total of \$25. The initial machine was nowhere near as impressive as today’s monsters. It consisted of two hollow half-discs, enclosing a magnet in the middle—something like a mess-kit you may have seen, as a Boy Scout or Girl Scout or in the military; a couple of small pie-tins, one acting as a lid for the other, then cut in half with the straight edges facing one another—leaving a small gap between the two halves. It could be held in one hand.



Drawing for Lawrence's cyclotron patent

When Lawrence first induced it with 2,000 volts he accelerated a tiny, curving, outward-spiraling particle-beam to about 1% of the speed of light when it reached the opening at 80,000 electron volts (not even 20% of the energy contained in a single electron). Due to its success it grew quickly in size and cost. Soon the cyclotron became a great circular tube wound around large, powerful electromagnets. Particles, a stream of protons usually, are fired from a source into the tube. As they proceed through the course they are bent to match the circle by strategically placed magnets, timed in pulsations to increase the speed of the protons as they pass again and again, each time accelerating them until they are boosted to a considerable percentile of light speed. Once the desired



(or maximum) velocity is attained the stream of protons are released through a straight tube to strike a carefully arranged target (the experiment) so as to knock pieces from its constituent atoms. The physicists set up detector systems that can follow the traces of the resulting particles. After many thousands of such smashings, they accumulate sufficient information about trajectories of the various sorts of debris, bent under the influence of magnetic fields of carefully controlled strength, such as to warrant calculating sizes and masses and speeds of the blasted shards by the length of their traces and the degree of curvature in their apparent courses. At first these subparticle ‘trajectories’ were displayed by cloud chambers and bubble chambers, wherein the particles could be indirectly seen by what were essentially condensation trails, even though the particles themselves are too small even to have an image. Much better imaging methods are used today as these powerful accelerators morphed into behemoths like that at CERN, in Switzerland, and at Fermilab, west of Chicago, where the Tevatron has reached beyond a trillion electron volts (TeV). In the early 1960s Stanford University built their linear accelerator, still the longest straight-line accelerator in the world at nearly two miles. [*Possible Field trip to SLAC with Lanny &/or to Berkely Lab – or maybe a Lawrence Livermore intro tour with Ralph?*] But we’re getting a little ahead of our story.

WWII—Enter: The Nuclear Age

A word first about the two modern world wars: WWI resulted from the still unsettled borders of emerging nations, the drive for expansion and struggles over access to sea ports, as well as ethnic conflicts that disrespected such borders as were artificially negotiated by the Congress of Vienna and maintained by a complicated web of separate and secret treaties between what were called the great powers. The result was not unlike the pressure building inside a boiler suddenly released when the strength of the container is surpassed at its weakest point, distorting the containment structure and causing it to fail. Triggered by the infamous assassination of Archduke Ferdinand in Sarajevo, the first declaration of war launched the unstoppable mobilizations in accordance with the secret pacts. It would be called the ‘war to end all wars’ not only because it was horrible beyond all imagination, but because it was thought the result would be a final settlement of Western, if not world politics. Unfortunately that hope or rationalization was futile. The Great War did not settle anything. Rather it ended (or in my view, merely took a time out) due to the sheer exhaustion of the participants. Of course it was the Central Powers (i.e., Germany) who surrendered due to the entry of the New World into the fray.

The Treaty of Versailles determined that Germany, as the loser, would have to pay for the damage and the new League of Nations (sans America, despite the fact that it was President Woodrow Wilson's pet idea) set about enforcing the reparations. Of course Germany, now governed by the newly established Weimar Republic, couldn't afford to repair itself, let alone reward the 'winners' who were at least as ruined. With the ruination of the Weimar Republic and Hitler's transformation of Germany into the Third Reich the possibility of renewed warfare arose, especially as the German re-armament movement was met with the unrealistic policy of disarmament by the League-associated nations as well as re-isolation and demilitarization by the USA. Thus was Hitler encouraged to enlarge his borders; to take in as much of the German speaking world as possible, before attempting ultimate world domination. The response of the Anglo-French-Scandinavian world was characterized by the Neville Chamberlain position that Hitler is a reasonable man and we can negotiate 'peace in our time'. We know how well that worked out. So the Second World War was in reality the resumption of WWI, with the exception of the additional war in the Pacific engendered by Japanese expansion through military conquest, a quite separate issue in nature from the war in the west, except that it greatly taxed the young Soviet Union and, eventually, the Americans by requiring them to fight two great wars, simultaneously, on opposite sides of the Earth. Russia had been at war with Japan off-and-on for a long time over territories and fisheries and trade and the US was a rapidly rising rival in the Pacific since expanding into the western territories of North America. So, while it was Japan who first attacked American soil in the territory of Hawaii, causing the Americans to declare war, it was a non-aggression pact between Japan and Hitler (so they would be free of mutual interference to create a seriously weakening split in Soviet military forces) that caused Germany to declare war upon the United States, drawing America into the Allied camp.

Had the League of Nations not effectively disarmed its members, especially France, rationalizing that lack of guns would result in lack of violence, and if the USA had joined much earlier in the effort to resist Germany, Hitler almost surely would have been checked and the war in Europe might have been shortened or even avoided by negotiation, as Chamberlain expected. But the lesson here is that one cannot negotiate from a position of obvious weakness. War, it seems, with nations or political entities of any sort who see that their needs or desires for something might be satisfied through conquest, is only avoidable by the factor of fear that they might lose everything in the attempt. If they are not afraid, they will take whatever they want. As Germany and Japan took more and more without reprisal they continued to want more and more. By waiting as each of these monsters developed their power and resources, the eventual Allies would guarantee their own enormous efforts and terrible costs when they finally found it necessary—almost too late—to resist. Why is that such a hard lesson to learn and to retain? But that is a question for a different study. What we want to know here is how the modern world, especially in terms of science and technology, was affected by the war.

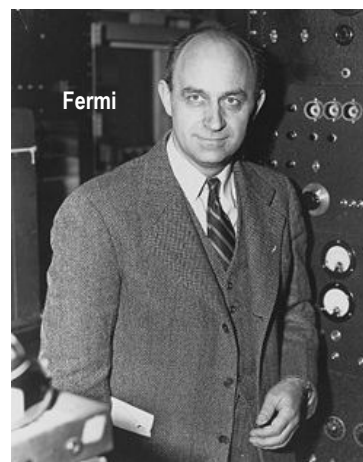
When quantum mechanics was in its infancy and relativity was first widely publicized, mainly through the explanation by Eddington, such concepts were thought, by the few folks who had even heard about such things, to be understandable only by particular geniuses like the iconic Einstein. Since then we have discovered that the quantum world is not really understandable at all. We have simply come to accept its paradoxical nature. But in the 1920s and '30s these things were not unlike magic to most

people and were generally considered to have hardly any practical consequences. Even among the physics *avant-garde*, as both ideas were still purely theoretical, no one knew where they would lead and there was little if any expectation that they would deeply affect the other sciences. If any large and costly experiments were considered, the continuing Great Depression put its damper on the idea.

The great divide between classical physics and what we now will call ‘modern physics’ really began to open during the 1930s when the possibility of transforming heavy elements into lighter ones by nuclear fission was seriously considered. Here was where the magic of $E=mc^2$ came to the fore. If the equations were correct, as the limited experimental data seemed to confirm, there was almost unbelievable energy stored in the nuclei of atoms, energy that might be utilized, if it could be released and controlled. While lighter elements might well be transformed to some limited degree, raising their atomic numbers by bombarding their nuclei with neutrons, most physicists believed the actual splitting of the nuclei of heavier elements would be impossible.

In 1938, however, as the self-appointed new War Minister Adolph Hitler was conquering Europe and building concentration camps in preparation for a ‘final solution’ to the Jewish problem, and Japan was absorbing Korea and invading China, and Orson Welles was panicking the eastern seaboard with his fictionalized newscast of a Martian invasion of Earth [adapted from H.G. Wells’ *WAR OF THE WORLDS*], German chemists Otto Hahn and Fritz Strassmann reported that they had detected barium after conducting uranium bombardment experiments. Lise Meitner (probably in Copenhagen at the time) interpreted this as evidence of nuclear fission and notified Niels Bohr who was in America lecturing at Princeton where Einstein was already on the faculty, having emigrated in 1933. It was Bohr who then brought the fateful news to **Enrico Fermi** [1901-1954] at Columbia University.

Fermi had just arrived at Columbia from Italy when fascist dictator Mussolini posted his Manifesto of Race. Fermi’s wife, half Jewish, was thus threatened. The law also deprived Fermi of most of his research assistants, seriously hampering his work on new radioactive elements and nuclear reactions to neutron bombardment, for which he had just received the Nobel prize. During this work Fermi and his team had not noticed the production of barium. They may not have used uranium as a target. Later, in 1954, the year of his death, Fermi would recall:



I remember very vividly the first month, January, 1939, that I started working at the Pupin Laboratories [Columbia Univ.] because things began happening very fast. In that period, Niels Born was on a lecture engagement at the Princeton University and I remember one afternoon Willis Lamb came back very excited and said that Bohr had leaked out great news. The great news that had leaked out was the discovery of fission and at least the outline of its interpretation. Then, somewhat later that same month, there was a meeting in Washington where the possible importance of the newly discovered phenomenon of fission was first discussed in semi-jocular earnest as a possible source of nuclear power.

[S.K. Allison; E. Segre; & H.L. Anderson: *Enrico Fermi 1901-1954 in Physics Today* (1955)
quoted in http://en.wikipedia.org/wiki/Enrico_Fermi]

War in Europe was already being rekindled by the Hitler expansion and leading theoretical physicists were flowing out of Germany and Italy on the wave of anti-Semitism engulfing Europe. By this time, though none of their names had achieved the household-word status of Albert Einstein, the world of science and industry was coming to recognize their worth and American universities began vying with one another to engage them as magnets to attract funds and students; bed-rock on which to found formidable physics departments. The wealthier Atlantic coast schools were the first to benefit, Princeton scoring the great Einstein himself; Fermi accepting a position at Columbia. There were many others who came seeking shelter and conditions under which they could work:

***Hans Bethe** went to Cornell. Being of Jewish ancestry, like many of the others, he had lost his job at the University of Tübingen and quickly headed to England in 1933 before emigrating to the USA in 1935. Known mainly for his theory of stellar nuclear-synthesis and what to expect in the life of stars of various classification (which we will refer to again in a future session), he was encouraged by Edward Teller to join with Robert Oppenheimer in the instigation of the Manhattan Project. A self-proclaimed ‘inconsistent pacifist’, he originally thought (and hoped) the A-bomb would be a failure. Then, however, as head of the theoretical division at Los Alamos, he helped solve the problems, particularly in the implosion mechanism, that dashed his early expectations. After the war, despite his protestations against nuclear war, he helped Teller develop the hydrogen bomb, though he again joined the program with the hope of proving such a weapon could not be made, further rationalizing that the research itself was of extreme importance in physics, that this was part of his career, and if he didn’t do it someone else would. Later, in the 1960s, he would join with a growing number of scientists in favor of banning nuclear testing;*

***Edward Teller** left Budapest to study chemical engineering in Germany. Then emigrated to Denmark and worked in England before migrating to the US, making his mark, too, at Los Alamos and eventually becoming “Father of the Hydrogen Bomb”;*

*Astronomer **Walter Baade**, a German immigrant who, with Franz Zwicky, theorized that neutron stars might be formed out of supernovae. Benefitting from the WWII black-out on the West Coast, he used Mt. Wilson to improve resolution of cosmic objects including the cepheid variables and doubled the size of Hubble’s universe;*

***Franz Zwicky** was a Bulgarian native who studied mathematics and physics in Zurich. He was not chased from Europe, like many of the others mentioned here, but left before the gathering of NAZI storm clouds was seriously noticed. Having received a Rockefeller fellowship in 1925, he emigrated from Switzerland to join Robert Millikan at Caltech, where he became renowned for his work in astronomy and astrophysics, discovering over 120 supernovae himself at both Mt. Wilson and the Palomar observatory. He was the first to theorize about dark matter and gravitational lensing and is mainly responsible for the ‘tired light’ hypothesis to explain the Hubble red shift without cosmic expansion. He began an extensive catalogue of galaxies and clusters that is still in use and being expanded today. He also excelled in rocketry and designed some of the earliest jet engines as a consultant for Aerojet Engineering Corporation.*

***James Frank** worked with Born in Göttingen and escaped to Johns Hopkins, then to Chicago where he, too, joined the Manhattan project;*

Maria Goeppert (Mayer), a student at Göttingen of Born and Frank who married Frank's assistant Joseph Edward Mayer, an American, and moved with her new husband in the early '30s to Johns Hopkins, then Columbia, then to Chicago and the Argonne National Lab., spent some time at Los Alamos and with Teller working on the hydrogen bomb and ultimately winning a Nobel for her mathematical model of nuclear shells;

*Then there was of course **Wolfgang Pauli** who took refuge with Einstein at the Institute for Advanced Study at Princeton, and **Niels Bohr** who also worked at Los Alamos in connection with, though not directly on design of, the atomic bomb, and **Erwin Schrödinger**, who was mentioned earlier as finishing his career in England;*

*The Viennese physicist **Victor Frederick Weisskopf** who did postdoctoral work with Heisenberg, Schrödinger, Pauli, Bohr and others, also escaped from Hitler and worked on the Manhattan Project, later to join with Oppenheimer and many other atomic scientists to try prevent more nuclear weapons and made great contributions to QED;*

***Emilio Gino Segré**, Italian Sephardic Jew and student of Enrico Fermi who became director of the University of Palermo physics laboratory in the late '30s, visited Lawrence's UC Berkeley Radiation Laboratory physics department, after which he was sent a molybdenum strip that was radiating strangely and he was able to discover it was due to a new element: the first (technetium) of many, soon-to-be-discovered, artificially manufactured elements that do not occur in nature. In 1938 he returned to Berkeley on a visit and while he was in California the Mussolini anti-Semite law was enacted that barred Jews from university positions. Unaware of his predicament, Lawrence offered him a research assistant position at \$300/mo., an offer that would have been insulting to a man who was not only a laboratory director himself but a renowned physicist who had discovered an element. He was not in a position to quibble, however, and when Lawrence discovered that Segré was in a political pickle, he cut his salary to \$116/mo. While there, Segré discovered another artificial element, astatine, and the isotope Plutonium-239 that made possible the atom bomb called Fat Man: the plutonium implosion type weapon used on Nagasaki;*

*In 1930 the great mathematician **John von Neumann**, of 'econometrics', computer development, and set theory fame, emigrated to the USA with his mother and two brothers and, in 1933, was offered one of the first five professorships at Princeton's Institute of Advanced Studies, joining Einstein and Kurt Gödel. Having made himself an expert in quantum mechanics [THE MATHEMATICAL FOUNDATIONS OF QUANTUM MECHANICS (1932)] and in the mathematics of explosions, von Neumann would also do important work at Los Alamos, especially in designing the explosive lenses intended to compress the plutonium core for the 'Fat Man' A-bomb;*

*Mathematical philosopher and logician **Kurt Gödel**, famous for his mathematics incompleteness theorem, was also a native Austro-Hungarian. After the Anschluss, when Austria became part of Germany, Gödel was automatically a German citizen. Hitler extinguished his position at the University of Berlin and Gödel was forced to find new employment. Because of his previous interaction with the Jewish members of the Vienna Circle, though not a Jew himself, the University of Vienna turned down his application for a teaching position and the German army found him fit for conscription just before the breakout of WWII. Fearing the problems surely to be faced in attempting to disembark from a coastal European port, if one could even get there without the proper papers, and then the perils of a wartime crossing of the Atlantic, Gödel and his new wife*

managed a trans-Siberian railway crossing of the Soviet Union, sailed to Japan and crossed the Pacific to San Francisco and finally headed to Princeton by rail. What an adventure that must have been! But more about Gödel later;

***Eugene Wigner**, another Hungarian Jew turned Lutheran (whose sister, you may recall, married Dirac), was also plucked in timely fashion from the NAZIs in 1938. He and Hermann Weyl were responsible for applying group theory to quantum mechanics and Wigner was present at the University of Chicago for the ‘chain reaction’ breakthrough under Enrico Fermi. A pacifist by nature, like Einstein, he too was temporarily turned by the NAZI menace and was instrumental in the famous letter to Roosevelt concerning the building of the A-bomb;*

*The author of the ‘famous letter’ and, thus, directly responsible for the Manhattan Project, was **Leó Szilárd**, another Hungarian of significant Jewish ancestry, who also found his way to Berlin to study physics under Einstein, Planck, and Max von Laue. Also escaping persecution, he preceded Fermi at Columbia in 1938, and joined him in Chicago, as well as in the patent for the nuclear reactor. He may have been the first to realize the weapons potential of nuclear fission, but though he encouraged the making of the A-bomb and helped to design it, he began to worry about the tendency for the military to take over the project from the scientists. He tried to convince the US government not to use the bomb on civilians, but suggested they invite the Japanese to witness a test explosion in the hope of frightening them into surrender (the ‘Szilárd petition’). If he thought that had any chance of working it was disproven by their failure to surrender even after the Hiroshima blast, requiring a second actual attack. After the war, dismayed by the failure of his petition and the terrible destruction caused by the bomb, in 1947 Szilárd switched disciplines to work in molecular biology. Like von Neumann, however, he seems to have had the explosives bug and, in 1950, despite his expectation that nuclear weapons could not be controlled—or perhaps it was due to having given up all hope in humanity—he seriously proposed a cobalt bomb, which he thought might wipe out life on Earth. Instead, thankfully, after another change of heart, perhaps in answer to the detonation of the first hydrogen bomb (designed by others), he was encouraged to join with some other scientists to establish the Council for a Livable World. Incidentally, there was a lot of talk about a cobalt bomb in those days, but apparently it proved impossible—or it surely would have been made and tested by now, and had it worked up to Szilárd’s expectations, we wouldn’t be around to discuss it;*

***Chien-Shiung Wu**, after a long voyage from China, enrolled in graduate school at U.C. Berkeley under Lawrence. She married physicist Luke Chia-Liu Yuan after graduation and moved to the East coast where she taught briefly at Smith College before joining the heavies at Princeton as an experimentalist and then to Columbia, where she began doing research and development for the Manhattan Project. She helped to develop the process for separating uranium metal into the U-235 and U-238 isotopes by gaseous diffusion, a process done on a gigantic scale at Oak Ridge. Though it may seem strange, today, that a Chinese physicist would be working on the atom bomb project, one must recall that during WWII, and shortly thereafter—until Mao Tse-Tung and his Red Army drove Chiang Kai-Shek and his Kuomintang off the mainland—China was a US ally in the war against Japan, and there were several Chinese scientists pursuing nuclear physics (not necessarily a bomb) in America.*

In the West, among the very best known of the top quantists, only Heisenberg and Max von Laue, not being Jewish, remained in Germany among many others of the second rank. Even so, there was some suspicion at first over their interaction with the new physics, which Hitler referred to as ‘Jewish science’, trying at first to purge it from German universities in favor of ‘*Deutsche physik*’ and thus increasing the flow of serious modern physicists, even non-Jews, to the West. This is not to imply that Hitler was anti-science. Far from it! Though he seems to have had minimal understanding of it himself, the NAZI war machine thrived on the industry spawned by advancement of technology: the *Luftwaffe* and the *Panzer* tank corps; the work done on synthesizing oil; plus Germany led the way into jet propelled aircraft and rocketry with the development of the famous V2 missiles, courtesy of the world’s leading rocket scientist Werner von Braun.

Once it became known that nuclear fission might be feasible, Hitler changed his tune and charged Heisenberg with figuring out how it might be accomplished, ostensibly to obtain energy that would not depend on oil, which was becoming ever more difficult to import—especially when the non-aggression pact with Stalin was violated and the war expanded to two fronts. There is mythology but little evidence that Heisenberg, who was not a NAZI party member, may have purposefully dawdled and perhaps even set-up roadblocks to NAZI success in harnessing the nucleus and attempted to prevent the use of atomic energy in weaponry. Such a tactic would not have been easy to carry out. Heisenberg may have been a great original genius but the cat was out of the ‘box’, so to speak. He was surrounded with real NAZIs: some of them true believers who (otherwise) were not stupid and had a fair grasp of the new physics and they might notice that he was dragging anchor on the voyage toward atomic energy. There is no doubt that such a program was underway under the watchful eyes of Carl-Friedrich von Weizsäcker and Karl Wirtz, and guided by Heisenberg, though it was seeking nuclear energy to replace fossil fuels. The means, then, to a sustained and controlled nuclear reaction, i.e., a nuclear power plant rather than a bomb, was the official cover. Even were that the original goal, it was quickly supplanted by the attempt to build an atomic weapon. No one was fooled.

In America, and especially in Australia, with Japanese expansion in the Pacific, war was on everyone’s lips. Surely the political leaders and top military men understood the need for the USA to enter the conflict in Europe. But there was resistance among the people, already struggling with the economic depression and in an isolationist mood, particularly in light of the thousands of good men who had been lost in the ‘war to end all wars’ only two decades past. Roosevelt knew that taking the nation into war so soon again would be a tough sell. Worse, the military had been sadly neglected; in fact, largely dismantled with the relief of victory in WWI and the expectation that Woodrow Wilson’s successful push for the League of Nations would somehow make armies obsolete.

It was the Japanese attack, of course, that provoked the US into war, but in a strange way that seemed to promise only more of a burden on the Japanese military than they were already carrying with their wide-spreading Pacific empire. What advantage, except to the fame and glory of their military in executing the risky mission, could they have expected from the destruction of Pearl Harbor on December 7, 1941: the “day that will live in infamy”? It is true that they pretty much annihilated the US Pacific fleet, since practically all the major warships in the Pacific were gathered in the same place—except the aircraft carrier USS *Enterprise*, which was on its way there but suffered from mechanical problems and was thus spared from the Japanese attack. In hindsight (by

which this seems frequently to be the case) there was so much misunderstanding, missed warning signs, lack of intelligence (in both meanings of that term), and damnable coincidence as to suggest to conspiracy theorists that the US might have purposely drawn the Japanese into attacking, some even claiming FDR himself was involved, creating this dire situation so that, by means of the spirit of revenge and by apparent necessity, he could overcome the anti-war atmosphere and thus motivate America to get involved before it was too late in what was clearly already a world conflict (not unlike the more recent suggestion that the Bush administration was complicit in the 9/11 attack). However unlikely and unprovable that may be, the disaster at Pearl Harbor did serve to motivate the 'sleeping giant' to war. Due to his anti-aggression pact with Japan, as previously mentioned, Hitler automatically declared war on the USA (only making official what had been taking place in the Atlantic for many months with the intensifying scourge of German U-boats). Thus America was wrenched into war in both hemispheres.

In 1941 the world was still in the throes of the Great Depression. The American military had been reduced practically to insignificance since WWI, partly to cut government expenditures and partly due to the expectation there would be no more war. Plus there was a general attitude of isolationism: if Europeans could not remain at peace, they ought to be left to resolve their own problems. Upon the virtual total destruction of the already weakened force still left to the US in the Pacific by Japanese war planes, that attitude was quickly adjusted but the Americans were in no position to do much in the way of combat. Still, while it had seemed impossible politically to change the public's isolationist state of mind prior to the 'day of infamy', there was increasing speculation among American leaders that war might be inevitable. Though hopeful that Hitler would be satiated by a Germanic supra-national consolidation of some sort, they were not lulled thereby into a pacifist dreamland. Soon to spur crisis level development of atomic energy at the University of Chicago; Argonne National Laboratory; and ultimately the weapons race at Los Alamos and Oak Ridge, Tennessee, the idea of the big bomb, was already being entertained in 1939. Witness the letter drafted by Szilárd and sent to FDR by Einstein in reaction to information concerning the NAZI program.

Include copies of all four letters/excerpts with HANDOUTS: Albert Einstein's Letters to President Franklin Delano Roosevelt; © Glenn Elert, 1992-2008 as found on his site, E-World; see <http://hypertextbook.com/eworld/einstein.shtml>.

Heisenberg, unable (or unwilling) to initiate the necessary chain reaction and not certain whether he would be seen as a traitor to his country if he failed or a traitor to mankind if he were to succeed, eased his stress by playing Bach organ pieces in lieu of doing the calculations for the amount of U235 necessary for a successful atomic bomb. Meanwhile Fermi built the first reactor in a racquetball court beneath the west grandstand of Stagg Field, the old football stadium at the University of Chicago. The pile reached critical mass on December 2, 1942 (a year to the week after the attack on Pearl Harbor). "The Italian navigator has landed in the new world" was the code message sent by the project manager, University of Chicago Professor Arthur Compton to Harvard president James B. Conant, a member of the Manhattan Project Military Policy Committee.

It is probably fair to say that a substantial majority of the scientists working on the bomb project were pacifist by nature, but had been pushed beyond their ideological limits by enemy atrocities. Einstein, under permanent investigation as a possible communist by

J. Edgar Hoover's FBI because of his undisguised pacifism, was denied the necessary security clearance for working on the weapon despite it being his formula, $E=mc^2$, that led others to the correct recipe for nuclear fission. He is reputed to have said that the letter to FDR encouraging the development of atomic weapons was the greatest mistake of his life. But you may recall him saying that also about introducing his cosmological constant into the relativity equations. In that case, he found it easy enough to cancel the mistake—although, later, some cosmologists would find it was not such a bad idea at all and would reintroduce it. As for his 'mistake' regarding the A-bomb, once Germany had been defeated and an Axis weapon was no longer a threat, many of the physicists who had worked on the bomb joined in a recommendation that it not be used against Japan and urged discontinuance of the program.

On the other hand, the genie was already out of the bottle. The Soviet Union captured the largest part of the German program, except that Heisenberg and the group actually working on the reactor—and von Laue as well, though separately—were kidnapped by the British and spirited out of Germany to keep them out of Stalin's hands. The Russians would inevitably figure out how to build the weapon, speeded somewhat by a well paid spy at Los Alamos itself. And now, on the heels of the atomic bomb, a theory had already been advanced concerning the possibility of a fusion-type weapon.

It was pretty clear to all but true believers in communism (Marxist intellectuals in their ideological ivory towers, red-journalists like John Reed who had been blinded by Soviet propaganda, and the growing and agitating Communist Party in France) that the Soviet Union was *not* to be the last great hope of freedom and global democracy; that they would, in fact, have to (and certainly seemed willing to) *conquer* the world by violence in order to force the supreme benefit of Marxist-Leninist-Stalinist communism on humanity. Among those ideological true-believers were many of the very physicists who had created the terrible new weapon. They had done it, mostly, to beat Hitler to the nuclear punch. Now that the race had been won, the danger passed, they hoped to retract their work and escape from the verdict of history that could well stain their legacies with the indelible blotch of terrorism by nuclear incineration.

Genius pacifist atomic scientists, those with terrible and top-secret knowledge in particular, are not seen as harmless by nations at war. Prominent among those suspected,

Bohr believed that atomic secrets should be shared by the international scientific community. After meeting with Bohr, J. Robert Oppenheimer suggested Bohr visit President Franklin D. Roosevelt to convince him that the Manhattan Project should be shared with the Russians in the hope of speeding up its results. Roosevelt suggested Bohr return to the United Kingdom to try to win British approval. Winston Churchill disagreed with the idea of openness towards the Russians to the point that he wrote in a letter: "It seems to me Bohr ought to be confined or at any rate made to see that he is very near the edge of mortal crimes."

[found in http://en.wikipedia.org/wiki/Niels_Bohr]

They did not see themselves as traitors, but some did consider themselves world citizens: early globalists and thus anti-national in attitude. They merely wanted to share the weapons secrets in the interest of global nuclear parity: the 'mutual annihilation' theory that seemed the only hope of preventing one country from becoming the world bully. It didn't seem to faze them that the solution they were suggesting included handing the

secret of their nightmare bomb to the very worst of the world bullies. In fairness, it should be mentioned that the USSR, while secretive and disingenuous, was as yet only *potentially* the worst. In any case, the worried scientists found they no longer had influence over how the results of their project would be used. Many would lose their security clearances, in fact, for having mentioned such an idea, or even for remaining friendly with those who had. They were subjected to surveillance and restrictions in their employment, and they were barred, of course, from any further work in weapons development. Physics undeniably receives a big boost from the needs and policies and fears engendered by war, but it was now also threatened with a new problem: government involvement and control through public funding and national security worries. In the US, at least, with passage of the McMahon act, which placed nuclear knowledge under civilian control, it was tacitly acknowledged that there was more to the new science than weapons making as well as that such weaponry as was now possible could not be entrusted to judgment narrowly focused through the military lens.

We will see where that led in our next session.

HANDOUTS:

Albert Einstein's Letters to President Franklin Delano Roosevelt;

© Glenn Elert, 1992-2008 *as found on his site,*
E-World; see <http://hypertextbook.com/eworld/einstein.shtml>.

ALSO

Ch.7-10 *from* PARTICLE PHYSICS: A Very Short Introduction *by* Frank Close;
Oxford Univ., UK, 2004; pp.81-129

AND

List of particles *from* Wikipedia – http://en.wikipedia.org/wiki/List_of_particles (9 pages)

AND include the following print-out:

(This HANDOUT needs further editing, even in this state will serve only as some plain-language but authoritative background regarding the level of uncertainty at the ‘frontiers of particle physics’. In fact it might be pointed out that the mere name of this branch of the discipline implies the very billiard-ball mechanics the Copenhagen group and the Swiss patent office technician thought might need to be overthrown—well, at least that the old theories needed encompassing by something more complete and accurate: more ‘correct’ and thus, perhaps, more grand.)

The Three Frontiers of Particle Physics

Report of the Particle Physics Project Prioritization Panel – [The PPPPP hoping their recommendations might be funded]

What are the most basic building blocks of the universe?

What are the forces that enable these elementary constituents to form all that we see around us?

What unknown properties of these particles and forces drive the evolution of the universe from the Big Bang to its present state, with its complex structures that support life—including us?

These are the questions that particle physics seeks to answer. Particle physics has been very successful in creating a major synthesis, the Standard Model. At successive generations of particle accelerators in the US, Europe and Asia, physicists have used high-energy collisions to discover many new particles. By studying these particles they have uncovered both new principles of nature and many unsuspected features of the universe, resulting in a detailed and comprehensive picture of the workings of the universe.

Recently, however, revolutionary discoveries have shown that this Standard Model, while it represents a good approximation at the energies of existing accelerators, is incomplete. They strongly suggest that new physics discoveries beyond the Standard Model await us at the ultrahigh energies of the Terascale. The Large Hadron Collider will soon provide a first look at this uncharted territory of ultrahigh energy; a future lepton collider will elucidate the new phenomena with great precision. A striking development in neutrino physics is the discovery that the three kinds of neutrinos, which in the Standard Model are massless and cannot change from one type to another, do in fact have tiny masses and can morph from one kind to another. This discovery has profound implications not only for the Standard Model but also for understanding the development of the early universe.

The accelerating expansion of the universe, yet another remarkable discovery, implies the existence of a mysterious entity, a dark energy that makes up almost three quarters of the energy-matter content of the universe, driving it apart at an ever-increasing rate. Dark Energy has interesting properties that could change our understanding of gravity. Astrophysical observations have also revealed that about a quarter of the universe consists of an unknown form of matter called dark matter. No Standard Model particle can account for this strange ingredient of our universe. In the next decade, the combination of LHC results and dedicated dark-matter-search experiments promise to shed light on dark matter’s true character.

All these discoveries make the field of particle physics richer and more exciting than at any time in history. New accelerator and detector technologies bring within reach discoveries that may transform our understanding of the physical nature of the universe. A set of interrelated questions, articulated in several previous reports, defines the path ahead:

1. How do particles acquire mass? Does the Higgs boson exist, or are new laws of physics required? Are there extra dimensions of space?
2. What is the nature of new particles and new principles beyond the Standard Model?
3. What is the dark matter that makes up about one quarter of the contents of the universe?
4. What is the nature of the dark energy that makes up almost three quarters of the universe?
5. Do all the forces of nature become one at high energies? How does gravity fit in? Is there a quantum theory of gravity?
6. Why is the universe as we know it made of matter, with no antimatter present? What is the origin of this matter-antimatter asymmetry?
7. What are the masses and properties of neutrinos and what role did they play in the evolution of the universe? How are they connected to matter-antimatter asymmetry?
8. Is the building block of the stuff we are made of, the proton, unstable?
9. How did the universe form?

Physicists address these questions using a range of tools and techniques at three frontiers that together form an interlocking framework of scientific opportunity.

The Energy Frontier

Experiments at energy-frontier accelerators will make major discoveries leading to an ultimate understanding of particles and their interactions. Outstanding questions that present and future colliders will address include the origin of elementary particle masses, the possible existence of new symmetries of nature, the existence of extra dimensions of space, and the nature of dark matter. Experiments at the energy frontier, at the LHC and at a future lepton collider, will allow physicists to directly produce and study the particles that are the messengers of these new phenomena in the laboratory for the first time.

The Intensity Frontier

Measurements of the mass and other properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for the understanding of the evolution of the universe. The US program can build on the unique capabilities and infrastructure at Fermilab, together with the proposed deep underground laboratory at Homestake, to develop a world-leading program of neutrino science. Such a program, not possible at the large collider facilities, will require a multi-megawatt-powered proton source at Fermilab. Incisive experiments using muons, kaons or *B* mesons to measure rare processes can probe the Terascale and beyond.

The Cosmic Frontier

Ninety-five percent of the contents of the universe appears to consist of dark matter and dark energy, yet we know very little about them. To discover the nature of dark matter and dark energy will require a combination of experiments at particle accelerators with both ground- and space-based observations of astrophysical objects in the distant cosmos.

The three frontiers of research in particle physics form an interlocking framework that addresses fundamental questions about the laws of nature and the cosmos. These three approaches ask different questions and use different techniques, but they are ultimately aimed at the same transformational science. Discoveries on one frontier will have much greater impact taken together with discoveries on the other frontiers. For example, the discovery of new particles at the energy frontier, combined with discoveries from the intensity frontier about neutrinos and rare processes, may explain the dominance of matter over antimatter. Synthesizing discoveries from all three frontiers creates the opportunity to understand the most intimate workings and origins of the physical universe. ²³ *Report of the Particle Physics Project Prioritization Panel*

The Standard Model

The Standard Model is the best theory that physicists currently have to describe the building blocks of the universe. It is one of the biggest achievements in twentieth century science. It says that everything around us is made of particles called quarks and leptons with four kinds of forces that influence them.

[The world, then, at its foundation, consists of] six quarks and six leptons, and the carriers of the four types of forces that act between these particles. The most familiar forces are electromagnetism and gravity; the other two are less well known. The strong force binds atomic nucleons together, making them stable. Without it, there would be no atoms other than hydrogen: no carbon, no oxygen, no life. The weak force causes the nuclear reactions that have let the sun shine for billions of years. As a result, trillions of neutrinos come from the sun and go through our bodies every second; we don't feel them because the weak force is so weak.

Despite its incredible success, the Standard Model has serious deficiencies. For example, if forces and matter particles are all there are, the Standard Model says that all particles must travel at the speed of light—but that is not what we observe. To slow them down, theorists have proposed a mysterious, universe-filling, not-yet-seen energy field called the Higgs field. Like an invisible quantum liquid, it fills the vacuum of space, slowing motion and giving mass to matter. Also, physicists now understand that 96 percent of the universe is not made of matter as we know it, and thus it does not fit into the Standard Model.

How to extend the Standard Model to account for these mysteries is an open question to be answered by current and future experiments.

ELEMENTARY PARTICLES

*The Frontiers of our Science: Beyond the Standard Model*²⁴

The Tevatron Collider [FermiLab, Chicago] has a very rich program. It is actively searching for new physics in multiple promising channels. These include channels with either leptons or jets and missing energy. Large missing energy signatures are a characteristic of models with neutral stable particles, which may be candidates for dark matter. These particles are present, for instance, in many low-energy supersymmetric

extensions of the Standard Model. These searches have so far found no convincing evidence of physics beyond the Standard Model, although experimenters have observed a small but interesting excess of events in certain channels.

Another interesting signature accessible at the Tevatron is the resonance production of a pair of top quarks. Such signatures are characteristic of many models of new physics in which the third generation quarks appear more strongly coupled to new, heavy gauge bosons than are quarks from the first two generations.

The experiments also anticipate further precision measurements of the top quark and W boson masses and of the production rate for single top quarks as well as a variety of QCD, B physics and electroweak measurements.

Overview

When the Large Hadron Collider begins operating, it will open a new era in particle physics with discoveries anticipated that have the potential of revolutionizing our understanding of the physics of the universe. This proton collider will take a major step in accelerator performance, with an energy seven times higher than the Tevatron's. Two general-purpose LHC experiments, ATLAS and CMS, will probe the most basic interactions of nature. The smaller dedicated experiments LHCb and ALICE will help elucidate the origin of matter-antimatter asymmetry and of the quark-gluon plasma, respectively. Intense LHC commissioning activities have included two successful beam injection tests into the LHC ring and, more recently, first power tests of machine sectors up to almost the nominal current. These tests indicate that the accelerator will perform to design specification. The LHC is presently being cooled down to the operation temperature. CERN plans first beam injections in summer 2008, to be followed by first beam-beam collisions. The LHC will run at a center-of-mass energy of 14 TeV. The intensity, or luminosity, during the first few years of running will be a factor of six higher than the Tevatron's world record. The ultimate luminosity will be another factor of five higher. A further increase by a factor of ten, the so-called Super LHC, is planned, and will require detector and accelerator upgrades.

The installation of the four experiments in the underground caverns is essentially complete, and vigorous commissioning campaigns with cosmic rays have been underway for some time. In parallel, scientists are carrying out so-called "data challenges," massive simulations and world-wide distributions of event samples similar to those expected at the LHC, in order to finalize the software tools and to stress-test the LHC's Grid-based computing infrastructure all over the globe.

Physics program overview

The physics program planned for the LHC is broad, diverse and exciting. When the collider turns on at a low startup luminosity, measurements of the production rates and properties of QCD jets, photons, W and Z bosons, and quarks with heavy flavor will probe the Standard Model in a new kinematic regime. The large number of top quarks produced at the LHC will allow precise measurements of the top mass and top's couplings, and will permit sensitive searches for nonstandard top decays. Searches for rare or forbidden B decays will constrain possible extensions to the Standard Model. Studies of these processes will begin shortly after accelerator turn-on and will improve in precision with increasing data.

The most tantalizing possibilities for discovery at the LHC stem from the exploration of physics at the Terascale. There is by now strong evidence that the Standard Model is not a complete theory of the elementary particles and their interactions. Recent observations that dark matter is not made of known particles and that neutrinos have nonzero masses provide strong evidence for the existence of new physics. The Standard Model cannot give satisfactory answers to many key questions: Why is the universe made of matter, with very little antimatter? What is the relationship between gravity and the forces acting on elementary particles?

At the Terascale, physicists expect to discover new particles and interactions to address these Standard Model problems. The most urgent question concerns the nature of electroweak symmetry breaking, the as-yet-unverified mechanism that generates particle masses. The LHC experiments will conclusively test the Standard Model answer to this problem, the Higgs mechanism, by looking for the Higgs boson over the fully-allowed mass range. With about 1 fb^{-1} (one inverse femtobarn) of well-understood data, likely available by 2009, the absence of a signal would exclude the existence of a Higgs boson. If the Higgs boson exists, on the other hand, $0.5\text{-}5 \text{ fb}^{-1}$ are needed for discovery, depending on its mass. LHC experiments would observe the Higgs in a number of decay modes. The increased collision intensity of SLHC will test whether the new particle is indeed the Higgs boson. Alternative models call for several Higgs bosons (or even no Higgs boson). If the experiments find more than one, the non-Standard-Model origin of the Higgs will be clear. If there is no Higgs boson, other new phenomena should appear. In this case, detailed measurements would require the higher collision intensities of the SLHC.

Physicists have developed several candidate theories for physics beyond the Standard Model over the past decades. They often predict a rich array of new particles and interactions. ATLAS and CMS, with their direct discovery reach for new particles extending up to masses of 5-6 TeV, will tell us which, if any, scenario is correct. They should also be able to perform precise measurements of newly discovered particles and phenomena, providing insight into the underlying new theory.

Supersymmetry, often referred to as SUSY, is among the most promising scenarios for physics beyond the Standard Model. An intriguing SUSY feature is that the lightest supersymmetric particle, the neutralino, is the best candidate today for dark matter. If Terascale supersymmetry exists, then the LHC will produce copious quantities of neutralinos. In such a scenario, the LHC would become a dark-matter factory. Within

the wide range of existing SUSY models, the predicted masses of the SUSY particles and their dominant decay modes depend on a number of phenomenological parameters. Analyses of Monte Carlo samples by ATLAS and CMS have demonstrated both experiments' ability to observe SUSY, if the mass of the SUSY particles is less than a few TeV, and to perform precise measurement of SUSY parameters. Such measurements could have important cosmological implications, providing insights into the physics of the early universe.

Theories aimed at unifying gravity with the other forces that affect elementary particles generally require more than three spatial dimensions. In these theories, the additional spatial dimensions are too small to observe at the energies of past accelerators. In some such theories, the LHC has sufficient energy to allow experiments to observe the effects of these extra dimensions. The signatures vary with the details of the model, but often include the production of events with large apparent missing transverse energy and momentum, in conjunction with high-momentum jets of particles or with leptons of high transverse momentum. If these theories are correct, the LHC would have profound effects on our understanding of the nature of space-time. It would provide the first experimental evidence for a unified theory of gravity and quantum mechanics.

Probing Dark Energy and Cosmic Acceleration

In 1998, two independent teams studying distant supernovae made the surprising discovery that the expansion rate of the universe is accelerating. Subsequent observations of the cosmic microwave background radiation anisotropy and of the large-scale distribution of galaxies, as well as observations of clusters and more recent supernova measurements, have independently confirmed and amplified this remarkable finding. According to Einstein's theory of general relativity, if the universe is filled with ordinary matter, gravity should be slowing down its expansion. Since the expansion is instead speeding up, we are faced with two possibilities, either of which would have profound implications for our understanding of the cosmos and of the fundamental laws of physics. Either three quarters of the energy density of the universe is in a new form called dark energy, or general relativity breaks down on cosmological scales and must be replaced with a new theory of gravity.

Cosmologists have suggested a variety of theoretical ideas to explain dark energy. It could be the energy of the vacuum, equivalent to Einstein's cosmological constant. Although sometimes considered the simplest model for dark energy, conventional particle physics theory predicts that the vacuum energy density should be at least 50 orders of magnitude larger than the value that would account for the present acceleration. Alternatively, dark energy could signal the existence of a new, ultra-light particle with a mass of order 10^{-33} GeV, an idea sometimes dubbed quintessence. Or cosmic acceleration could instead be signaling the need to revise Einstein's 90-year old theory of gravitation, or something else entirely new and unexpected. While the nature of dark energy is unknown, a well-defined set of first questions has emerged: Is dark energy the cosmological constant? Is it energy or gravity? Do its properties evolve over time? The major goals of dark energy experiments will be to address these fundamental questions.

A convenient way of describing the physical properties of dark energy is through its equation of state, the ratio of its pressure to its energy density. Future dark energy experiments will determine this ratio, and whether and how it evolves with cosmic time, with much greater precision than present experiments have achieved. These experiments will probe dark energy by studying its impact on both the history of the cosmic expansion rate and the growth rate of large-scale structure. In general relativity, the expansion rate, along with the properties of dark matter, determine the rate at which structure forms; departures from Einstein gravity may thus be tested by comparing the expansion rate history with the history of structure growth.
