

SSC design goes to DOE: ICFA discusses CERN hadron collider

Early in May a report containing reference designs for the Superconducting Super Collider was submitted to the Department of Energy. A group of about 150 scientists, led by Maury Tigner of Cornell, submitted a 400-page draft report that considered three SSC designs—one using 3-tesla superferric magnets (proposed by a Texas consortium), one using 5-tesla superconducting magnets (proposed by Fermilab) and one using 6.5-tesla superconducting magnets (proposed by Brookhaven and Lawrence Berkeley Lab). Cost estimates for each of the three designs were roughly the same: \$2.7–\$3.0 billion in 1984 dollars. These estimates do not include the cost of site acquisition or the cost of the detectors.

While the pace was quickening in the US for the SSC project, the International Committee for Future Accelerators was holding a conference with about 100 participants in mid-May at KEK in Japan. This conference was a sequel to the 1975 meeting in New Orleans, at which prospects for a "world accelerator" were first discussed. Last month's ICFA conference was called to strengthen interregional collaboration at this crucial time, according to Valentine Telegdi of ETH, who is chairman of ICFA. One suggestion relevant to the general discussion was the possibility of building a hadron-hadron collider in the LEP tunnel at CERN, a potential competitor for the US hadron-hadron collider.

Reference design for SSC. At a special session of the American Physical Society meeting in Washington on 26 April, Tigner described the SSC reference design and H. Guyford Steyer, president of the Universities Research Association, described progress in developing a management scheme for SSC. Late this month a workshop on SSC will begin at Snowmass, Colorado, (23 June to 13 July) for further SSC planning. This August, Department of Energy Secretary Donald Hodel will be presented with the reference designs report, an R&D plan and an R&D management plan; he will need to decide whether or not SSC should receive substantial addition R&D in

the FY 1986 budget, which is to be submitted to Congress next January. The R&D phase is expected to last three years from authorization. Construction would take an additional six years.

The reference design only considers a proton-proton collider (not a proton-antiproton collider) with 20 TeV in each beam and luminosity up to 10^{33} $\text{cm}^{-2} \text{ sec}^{-1}$. It has six intersection regions, with four being developed initially, and a 1-TeV synchrotron injector. The two rings would range from a 90-km circumference (just fitting within the "Beltway" around Washington) for 6.5-T magnets to 170-km circumference for 3-T magnets. The several-month design study was housed principally at LBL. "To show you how seriously Berkeley takes this," Tigner told the APS audience, "they have given all of us parking spaces."

Building on the experience gained in fabricating the Tevatron magnets at Fermilab (PHYSICS TODAY, March, page 17), Tigner said, the aperture of the magnets could be reduced to save money. The Brookhaven-LBL design has two side-by-side magnets, each with

a 6.5-T field and a 3.3-cm-diameter beam pipe.

The Fermilab design has two independent magnets (each with 5 T) for the two beams, and the beam pipe has a 3.7-cm diameter. Coils are held mechanically by aluminum collars.

The design developed by the Texas Accelerator Group (consisting of Texas A&M, Rice University, the University of Texas at Austin and the University of Houston) uses superferric magnets (with the field determined by the shape of the iron) operating at 3 T; it has two beam channels, one above the other.

To estimate the standard construction costs, Parsons, Brinckerhoff, Quade and Douglas (the architecture and engineering firm engaged) devised a canonical site that considered a variety of geological and topological conditions. This canonical site, like a jigsaw puzzle, had pieces representing hard and soft rock, glacial till, firm clay, sand silts and clays. It also incorporated a nearby highway, a railroad, an airport 80 miles away, and so on. Included in the final cost estimate are pieces for project management, central lab, injector, col-



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lider ring facility, 12 or 24 refrigerator buildings (depending on design), experimental facilities, systems engineering and design. For the 5- and 6.5-T magnets, about a million pounds of superconductor would be needed.

"There's just a supersweet project going there," Tigner concluded, with "no basic accelerator physics problems that we can find. Current accelerator practice scales reasonably well to 20 TeV."

The Universities Research Association (a consortium of 53 US universities and one Canadian university, which so far has mostly just managed Fermilab) has joined with Associated Universities Inc (best known for managing Brookhaven), the Texas Accelerator Group, Cornell, Stanford, the University of California (which runs LBL) and the University of Chicago (which operates Argonne). They have recently signed a memorandum of agreement, which would have URA as contracting agent with DOE. Boyce McDaniel has been named chairman of a Board of Overseers, whose most urgent task is to choose an R&D project director.

CERN plans. The hadron-hadron collider options for the LEP tunnel at CERN were expected to be a major topic at the International Committee on Future Accelerators meeting in May. The Large Electron-Positron accelerator at CERN, expected to produce first beam at the end of 1988, would, in its first phase collide leptons, with 50 to 60 GeV in each beam. In a recent telephone interview, CERN director Herwig Schopper told us that after LEP has its energy raised to 100 GeV/beam

and is exploited fully, CERN could in principle operate a hadron collider in the LEP tunnel. "The realization of such a hadron collider would require an immediate start on research and development," he said.

Last summer at the International Accelerator Conference at Fermilab, Schopper had outlined two extreme options for a hadron collider, which could be constructed by adding a ring of superconducting magnets on top of the LEP magnets in the 27-km-circumference LEP tunnel:

- a fast and cheap hadron collider, using Nb-Ti magnet technology to yield about 5 TeV in each beam
- a hadron collider that would take more time and money, requiring the

development of 10-T magnets to produce about 10 TeV in each beam.

A workshop of the European Committee for Future Accelerators met in Lausanne at the end of March to discuss these ideas in great detail, both from the experimental side (coordinated by Carlo Rubbia) and the machine side (coordinated by Giorgio Brianti). "No serious technical obstacles to the realization of the [hadron collider] ideas were found," Telegdi told us. Of the eight possible intersection regions at LEP, only four are being constructed now, and they are to be used for e^+e^- collisions. Because plans are to operate as a lepton collider for only 3000 hours per year, the rest of the time could be used to install the hadron collider, according to Schopper.

The potential for a European hadron collider (with the possibility of non-European participation being raised as well) might tend to speed up the international race for high-energy supremacy.

International cooperation. Presidential Science Adviser George Keyworth, speaking at the Fermilab users meeting on 27 April, said, "There's going to be only one supercollider in the world. And wherever that turns out to be will become the international center for much of experimental physics..." He hopes for "significant participation by other countries, too [in SSC]. We know foreign scientists will be an integral part of the research community using SSC; that goes without saying. We also want to benefit from their creativity in the construction phase as well. We've already been talking to our foreign colleagues." Keyworth mentioned his recent visit to Japan, expressly to invite "their interest at this earliest stage of our planning. Moreover, I hope that in the course of the London Economic Summit [this month] we'll

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have further discussions with our European partners."

Victor Weisskopf of MIT (a former CERN director), in his keynote address to the ICFA meeting in Japan (to be delivered by video recording), was to say that "an early drive at CERN to attempt the highest possible hadron energies in the LEP tunnel would jeopardize the chances to get the SSC in the US. American efforts towards an

SSC would make it much harder to get Western European governments to finance the use of the LEP tunnel for hadron collisions, in addition to the exploitation of lepton collisions by LEP I and LEP II....

"It is the duty of the community to come to a mutually acceptable solution. It is an issue of scientific responsibility versus scientific greed. But it is also an issue of wise policy towards the govern-

ments who pay the bill. We certainly will lose the support we have received in the past if it appears that different parts of the world community are trying to outpace each other and are no longer cooperating in the planning and construction of future accelerators, with mutual help and assistance. The danger is all the more acute since, even under the best conditions, this support is not assured." —GBL

Nuclear spin waves seen in dilute polarized gases

Spin waves in crystalline ferromagnets have been known since the 1950s. It is less obvious that such collective propagating modes of oscillating magnetization can be excited in liquids. But spin waves in degenerate Fermi liquids were predicted as early as 1958 and eventually seen in such Fermi-liquid systems as liquid helium-3 and the conduction electrons of paramagnetic metals.

In all of these systems the deBroglie wavelength of the constituents is at least comparable to the distance between nearest neighbors; there is sufficient overlap between wavefunctions so that the symmetrization required by the quantum statistics of identical particles is clearly significant. The quantum exchange interaction generated by identical-particle symmetrization is known to play a crucial role in the propagation of spin waves. It is not surprising, therefore, that the possibility of spin waves in non-degenerate dilute gases—where neighbors are much farther apart than their deBroglie wavelengths—was overlooked until quite recently.

Two years ago Claire Lhuillier and Franck Laloë at the École Normale Supérieure in Paris made a theoretical case¹ for the possibility of observing nuclear spin waves in dilute, nondegenerate gases of spin-polarized atomic hydrogen, deuterium and helium-3. Even in such rarefied systems, they pointed out, identical-particle symmetrization requires that the collisions by which nuclear spin perturbations diffuse through the gas have to depend on the relative spin orientations of the colliding particles, even if the interaction has no explicit spin dependence. This would introduce a precession of the spins of the colliding particles, giving rise in successive collisions to the coherent propagation of a perturbation introduced into the spin-polarized gas. It is not necessary that the deBroglie wavelength be as large as the mean interatomic spacing in the gas, they calculated; it need only be larger than the effective sizes of the atoms themselves. E. P. Bashkin at the Institute for Physical Problems in Moscow

made a similar prediction² at about the same time.

The existence of spin waves in a very dilute gas of spin-polarized atomic hydrogen has now been clearly demonstrated³ by David Lee, Jack Freed and their colleagues at Cornell. The striking pattern of resonant nmr peaks found in their experiment turns out to agree well with the spectrum of standing spin-wave modes predicted⁴ by Laurent Lévy and Andrei Ruckenstein (both now at Bell Labs), who reformulated the Lhuillier-Laloë theory in the quasiparticle language previously employed for degenerate Fermi systems, and emphasizing the essential identity of the physics of spin waves in the three seemingly disparate cases: ferromagnets, degenerate quantum liquids and dilute gases.

When he heard of the Cornell result, Laloë wrote to Lee: "As an ex-atomic physicist, I'm pleased to see that dilute systems—not just condensed matter—exhibit interesting quantum modes." There has been considerable skepticism, he pointed out, as to the possibility of seeing spin waves in a nondegenerate Boltzmann gas. "I'm pleased that you've now shown these arguments were pessimistic." In recent months, Laloë's experimental group in Paris has found⁵ less dramatic, but nonetheless convincing evidence for spin waves in spin-polarized helium-3 gas, and Wilfred Gully and William Mullin at the University of Massachusetts have made similar observations⁶ in a non-degenerate, dilute solution of helium-3 in liquid helium-4.

Spin-polarized atomic hydrogen is a particularly interesting system in which to look for spin waves. Whereas hydrogen atoms of opposite spin quickly combine to form molecular H_2 , hydrogen atoms of parallel spin experience only very weak mutual attraction. This, together with its low atomic mass, renders spin-polarized atomic hydrogen (usually written $H\uparrow$) the only material that is expected to remain a gas even at absolute zero temperature. Thus, as one increases its mean deBroglie wavelength $\lambda = h(2\pi/mkT)^{1/2}$ by lowering the temperature T ,

one can easily satisfy the Lhuillier-Laloë condition $\lambda \gg d$, where d is the atomic size, long before degeneracy effects become important.

As the deBroglie wavelength approaches the interparticle spacing at high density or low temperature, a fluid becomes degenerate. In a degenerate fluid of fermions, all quantum states well below the Fermi surface are occupied and hence inaccessible to newcomers. A degenerate fluid of bosons such as spin-polarized atomic hydrogen, on the other hand, would ultimately undergo Bose condensation to a single macroscopic quantum state. The effort to observe such Bose condensation has in fact been the principal impetus for the recent development of techniques to stabilize $H\uparrow$ at ever lower temperatures and higher densities (PHYSICS TODAY, June 1980, page 18).

At temperatures around 0.5 K and densities on the order of 10^{16} atoms/cm³, the $H\uparrow$ sample in which the Cornell group observed spin waves is still very far from Bose condensation. The thermal deBroglie wavelength (about 20 Å) is more than an order of magnitude smaller than the mean interatomic spacing, but it is significantly larger than the hard-core scattering size of the colliding atoms. The Cornell sample is held in a somewhat nonuniform magnetic field with a mean value of 77 kilogauss. In such a strong field at low temperatures only the two lowest-energy hyperfine states of atomic hydrogen are initially occupied. In the lowest-lying state ($|a\rangle$), the electron and nuclear spins are antiparallel, while the slightly more energetic $|b\rangle$ state has its electron and nuclear spins aligned. In both states, the great preponderance of electron spins are aligned opposite to the externally imposed magnetic field, but $|a\rangle$ has a small admixture of electron spins opposite to the majority. It is almost exclusively through this component that hydrogen atoms can combine into molecular H_2 . Thus, as the newly formed molecular hydrogen is removed from the sample by adsorption on the helium-4-coated walls, one is eventually left with nothing but the $|b\rangle$ state of