Encounters with Modern Physics

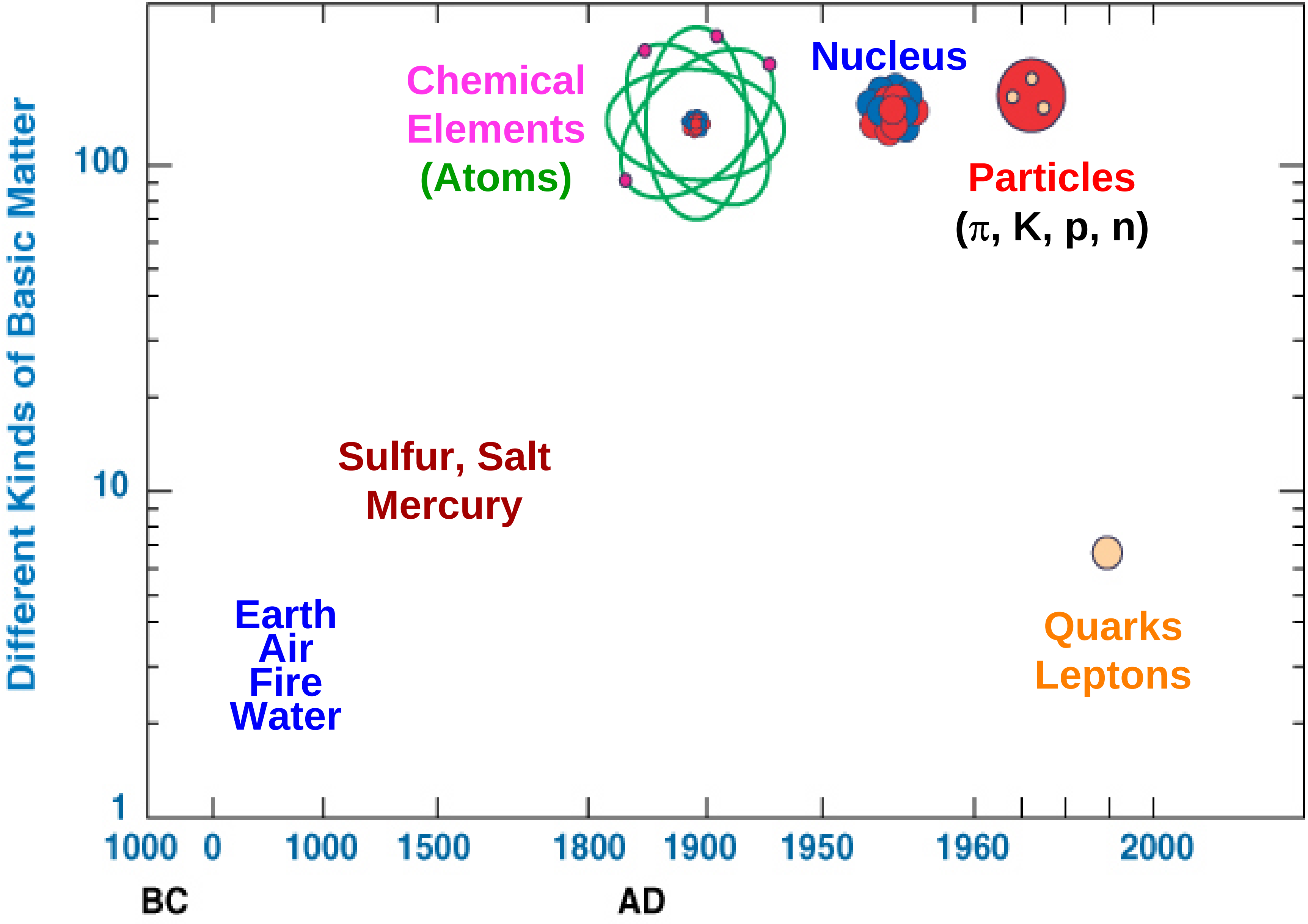
The Search for the Fundamental Building Blocks of Nature

Chinese University of Hong Kong

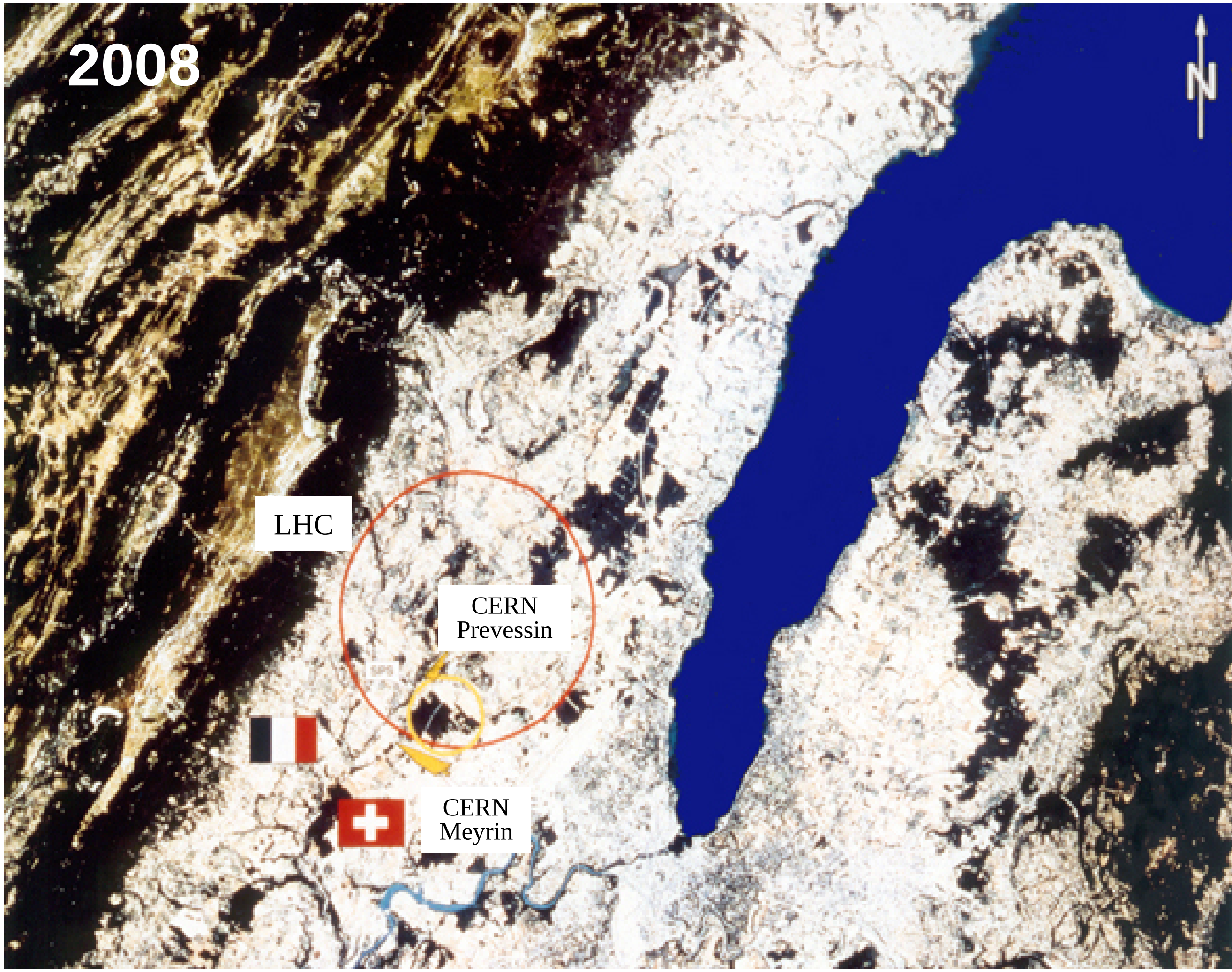
23 May 2006

Samuel C.C. Ting

History of Elementary Particles

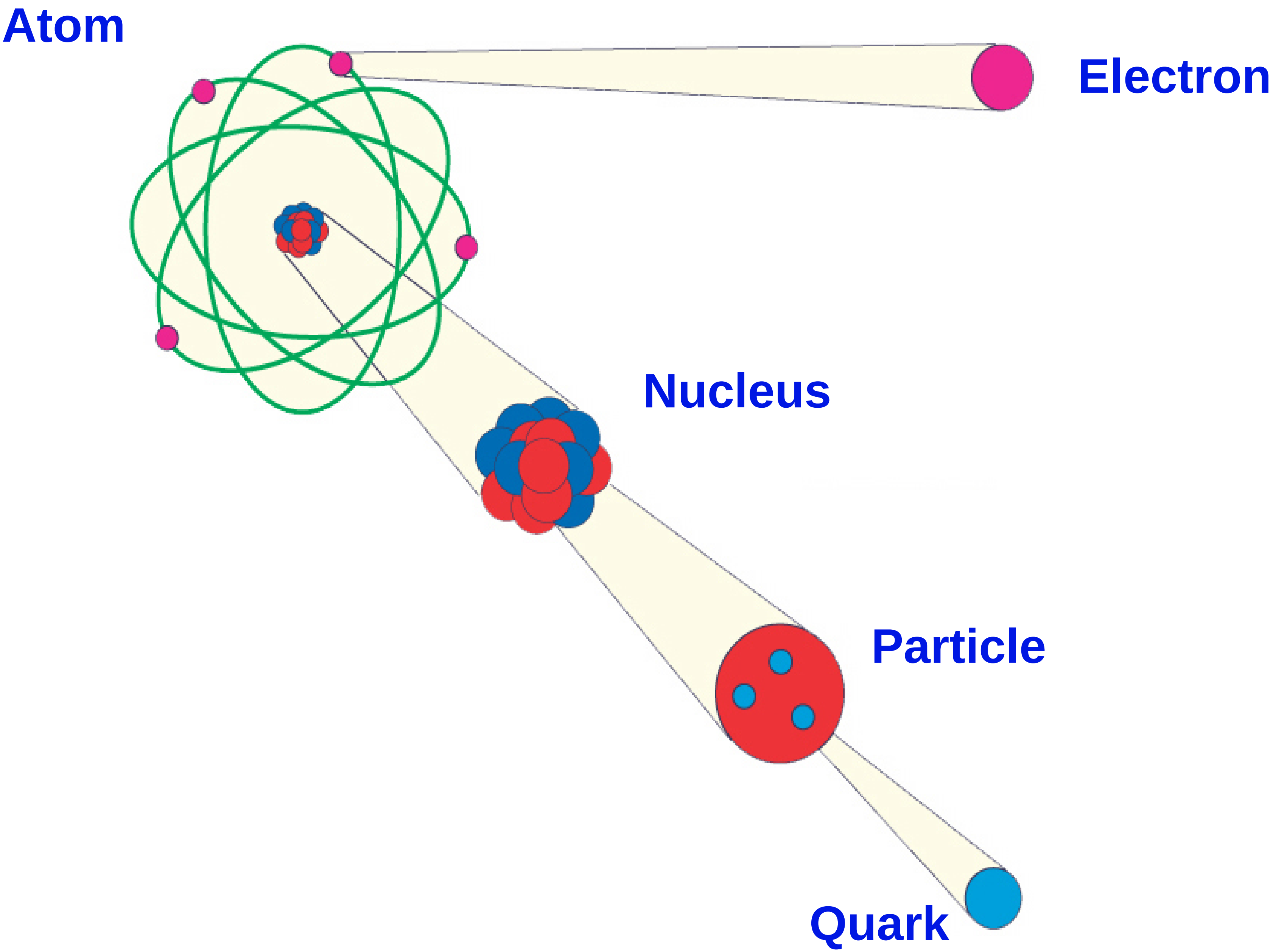


Development of Accelerators



Development of Accelerators

Source	*Energy (eV)*
Galileo, Tower of Pisa	0.0001
Bunsen, burner	1
Rontgen, x-ray tube	10,000
Lawrence, cyclotron	100,000
1950 synchrotrons	400,000,000
AGS, PS	30,000,000,000
Fermilab, SPS	400,000,000,000
LEP	70,000,000,000,000
LHC	100,000,000,000,000,000



Atom

Electron

Nucleus

Particle

Quark

Five short stories

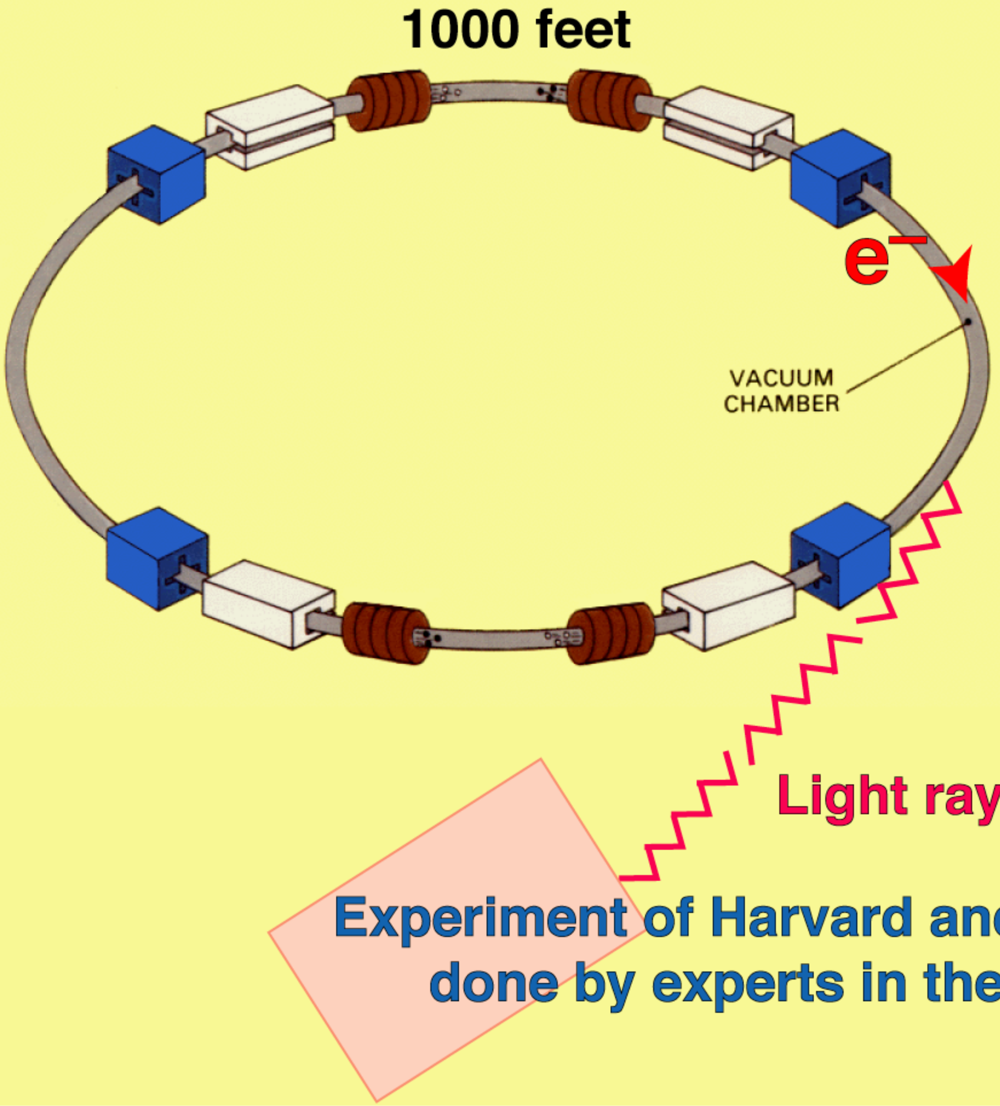
First Story:

1) Measuring the size of electrons

Modern electromagnetic theory (Feynman, Schwinger, Tomonaga - 1948) requires electron has zero dimension (in size)

The theory agrees well with all experiments until a large electron accelerator (built by Harvard and MIT in ~ 1960) provided a most sensitive measurement of the size of the electron.

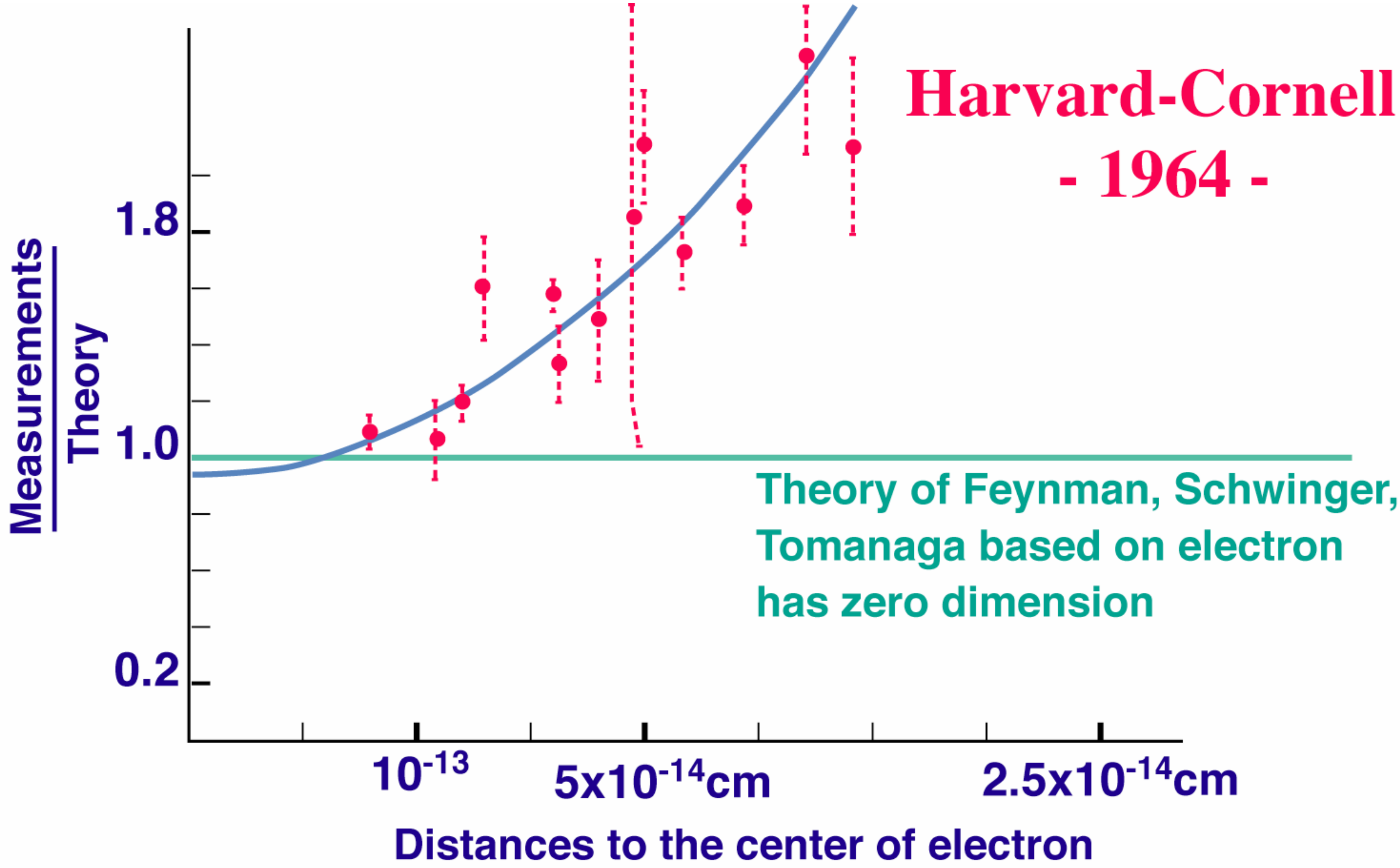
Cambridge Electron Accelerator 1964



Light ray of 6 billion eV

Experiment of Harvard and Cornell
done by experts in the field

y97332



Harvard-Cornell
- 1964 -

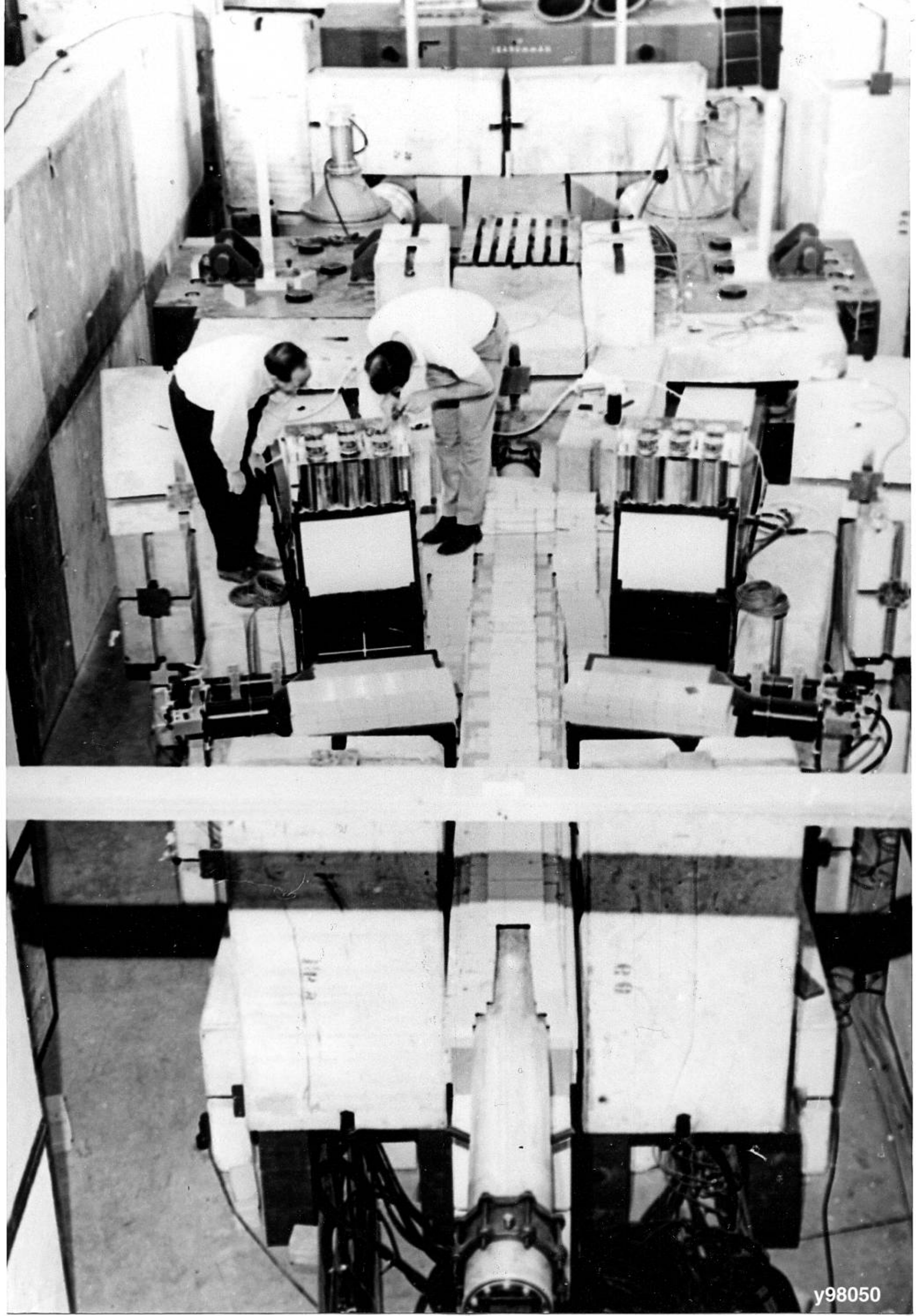
Theory of Feynman, Schwinger, Tomanaga based on electron has zero dimension

y97335b

Deutsches Elektronen - Synchrotron (DESY)
Hamburg, Germany

6 Giga electron-Volts (GeV) electron synchrotron

producing 10^{11} gamma rays/second



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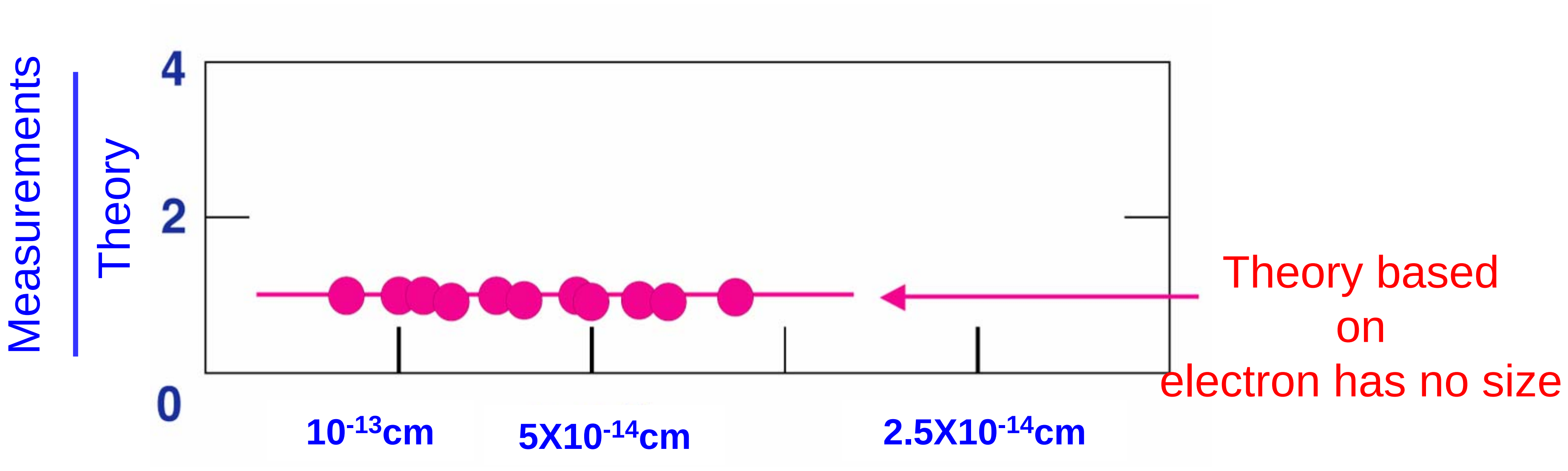
In 1966, I repeated the experiment in Germany with a different method and discovered that:

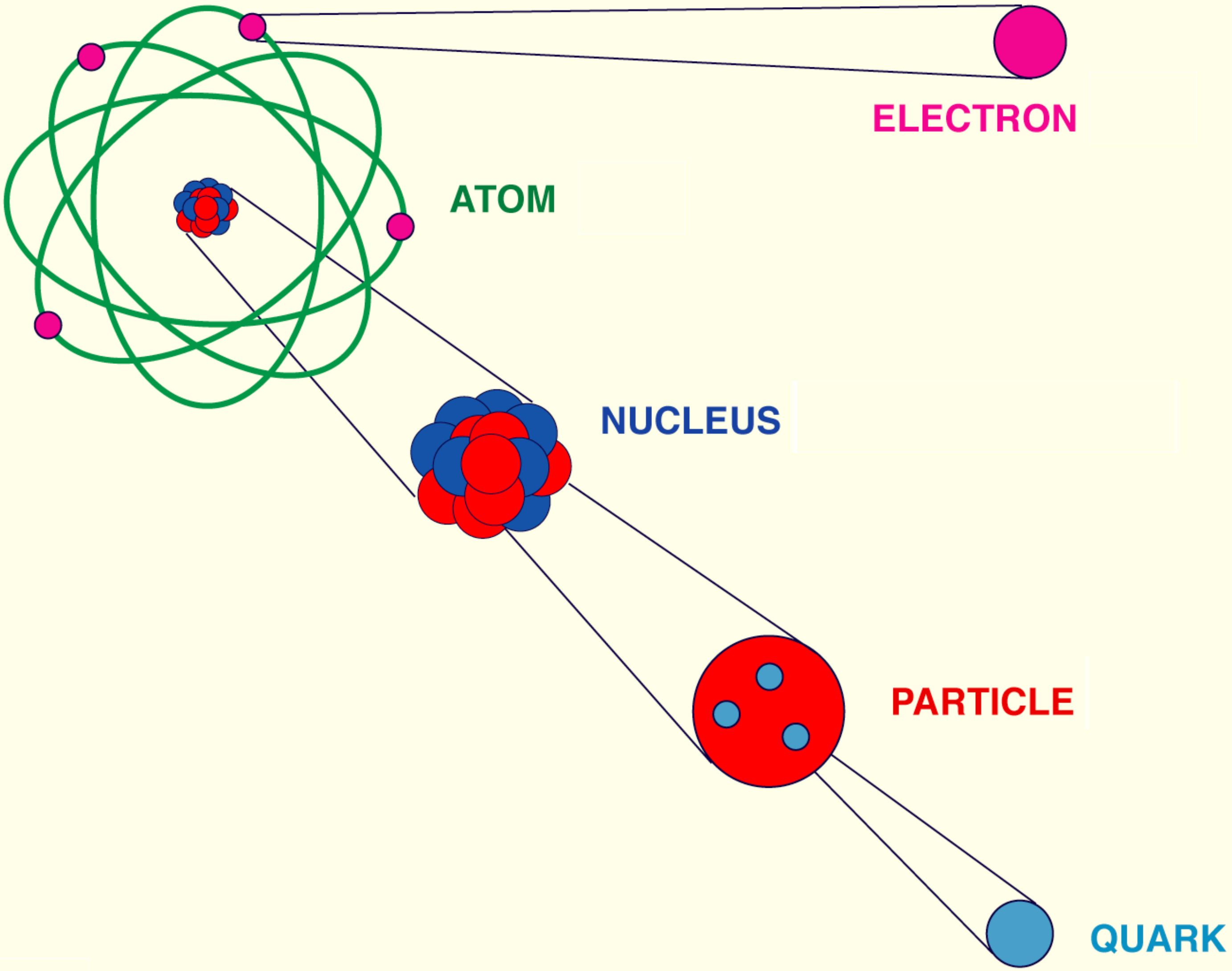
Electron has indeed no measurable size: Radius < 10^{-14}cm



Theory based
on
electron has no size

Lesson One:

Do not always follow the opinion of experts.



ELECTRON

ATOM

NUCLEUS

PARTICLE

QUARK

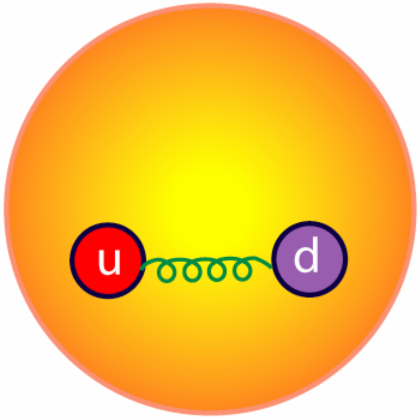
y94100

Second Story :

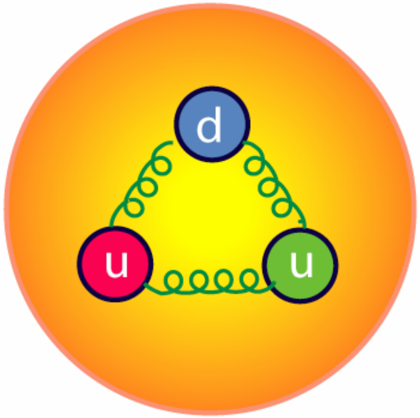
Discovery of a New Family of Quarks

By 1970, all the known elementary particles could be traced to 3 kinds of Quarks.

π+



Proton



I asked : Why only 3 kinds of Quarks ?

To look for New Quarks, I decided to set up a very sensitive detector with sensitivity :

$$\text{Sensitivity: } \frac{\text{New Quarks}}{\text{Old Quarks}} = \frac{1}{\text{10 billion}}$$

During a rainstorm over Hong Kong
there are 10 billion rain drops/sec.
Try to find the one drop that is different

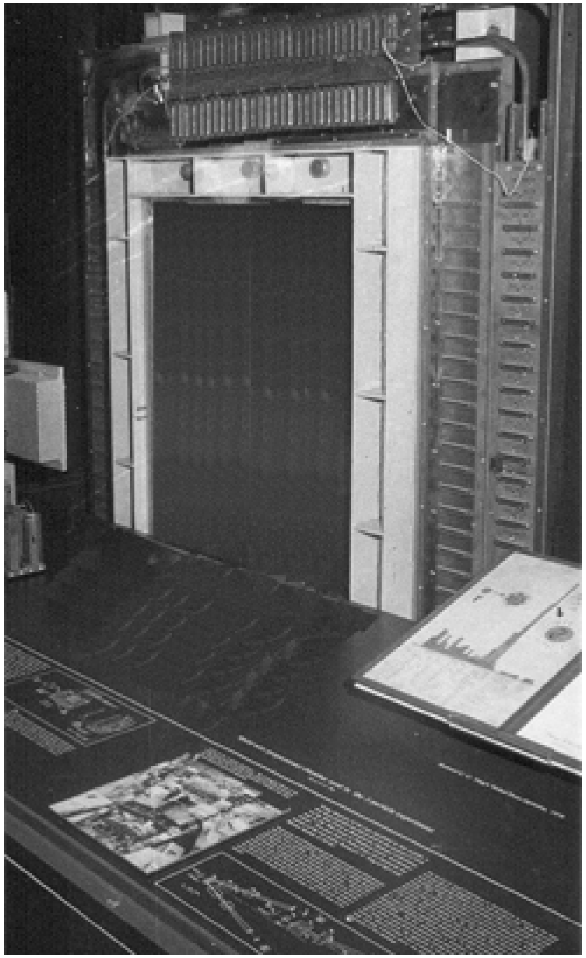
This experiment was not popular with Physics Community:
(1) Everyone believed there are only 3 kinds of Quarks;
(2) No one believed that such a difficult experiment
could be carried out.

So the experiment was rejected
by nearly every accelerator laboratory !

Brookhaven National Laboratory 1972 - 1974

Discovery of new form of Matter

1972 - 1974 The "J" particle spectrometer at BNL



Development of precise (100μm), radiation resistant (20 MHz) detector

(now at Smithsonian)

When we finally carried out this experiment at Brookhaven National Laboratory, NY, we did discover a completely new quark family.

It produces particles with unexpected properties:

(1) massive (heavier than known particles)

(2) extremely long lifetime (1000 times longer than known particles).

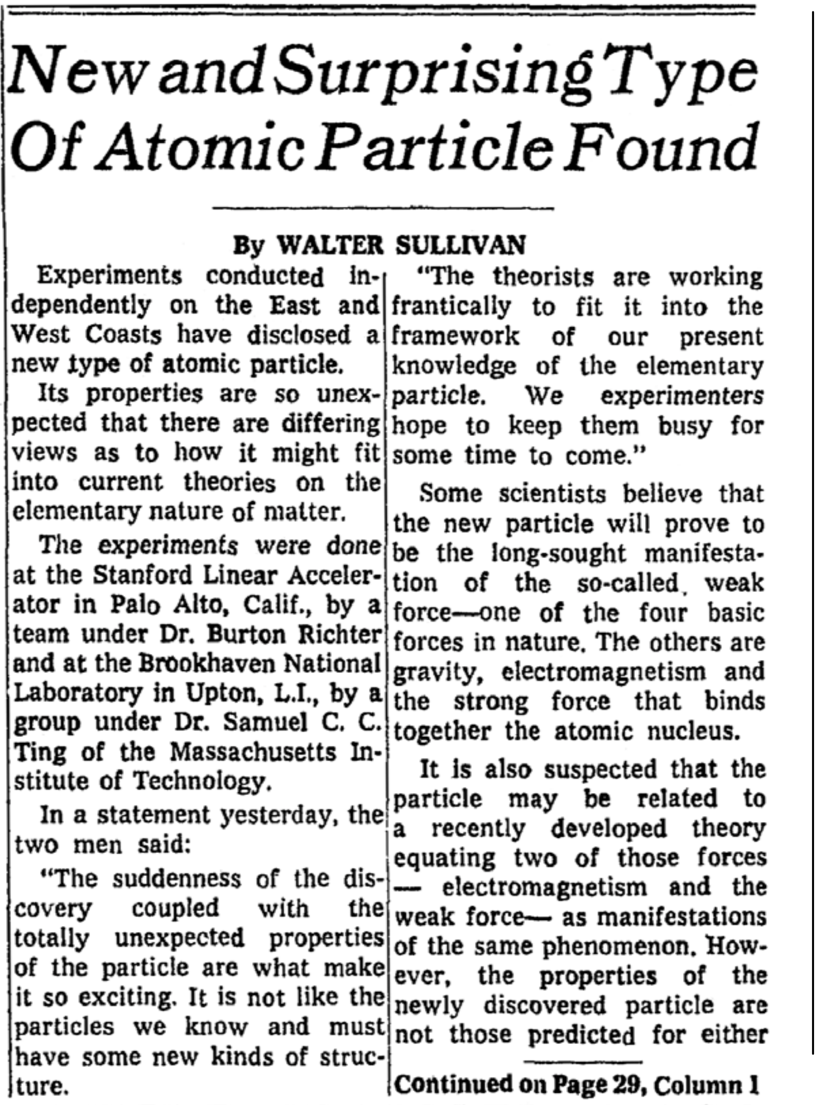
These properties imply the existence of new kind of matter (from new kind of Quarks).

Thus the concept of 3 kinds of Quarks was wrong.

We now know there at least 6 different kinds of Quarks.

The discovery of a new form of matter
New York Times, Nov 17, 1974, page 1.

New and Surprising Type Of Atomic Particle Found
By WALTER SULLIVAN
New York Times (1857-Current file); Nov 17, 1974; ProQuest Historical Newspapers The New York Times (1851 - 2002)
pg. 1



New and Surprising Type Of Atomic Particle Found

By WALTER SULLIVAN

Experiments conducted independently on the East and West Coasts have disclosed a new type of atomic particle.

Its properties are so unexpected that there are differing views as to how it might fit into current theories on the elementary nature of matter.

The experiments were done at the Stanford Linear Accelerator in Palo Alto, Calif., by a team under Dr. Burton Richter and at the Brookhaven National Laboratory in Upton, L.I., by a group under Dr. Samuel C. C. Ting of the Massachusetts Institute of Technology.

In a statement yesterday, the two men said:

"The suddenness of the discovery coupled with the totally unexpected properties of the particle are what make it so exciting. It is not like the particles we know and must have some new kinds of structure.

"The theorists are working frantically to fit it into the framework of our present knowledge of the elementary particle. We experimenters hope to keep them busy for some time to come."

Some scientists believe that the new particle will prove to be the long-sought manifestation of the so-called, weak force—one of the four basic forces in nature. The others are gravity, electromagnetism and the strong force that binds together the atomic nucleus.

It is also suspected that the particle may be related to a recently developed theory equating two of those forces — electromagnetism and the weak force— as manifestations of the same phenomenon. However, the properties of the newly discovered particle are not those predicted for either

Continued on Page 29, Column 1

ATOMIC PARTICLE IS FOUND IN TESTS

Continued From Page 1, Col.

of those roles.

"That a major discovery h been made became evident la Monday during a conversatic at the Stanford Linear A celerator between Dr. Wolfgar K. H. Panofsky, director of th two-mile-long device, and D Ting.

"I'd like to talk a litt physics," said Dr. Ting, as r called by Dr. Panofsky. F then told of recent experimer tal results obtained by himse and his colleagues.

"We just can't believe them he said. However, Dr. Panofsk said that essentially the san observations had been made his own laboratory.

News of the discovery h created a sensation in the wor of physics, and preparations a being made at CERN—the i ternational European Nucle Research Center outside G neva—to try to duplicate t discovery.

One possibility under discussion is that the new particle falls into a class, predicted by some theorists, that would display a combination of properties termed "charm." These properties would be distinct from those, known as strangeness, characterizing another family of particles. In the latter case, the name derived from what seemed the strange manner in which they form and decay.

However, it was found that they fell into a pattern that made possible predictions as to how each would behave. The same would be true of those displaying charm.

The new particle is one of the heaviest known. It was detected at the Stanford Linear Accelerator in experiments in which electrons and their positively charged counterparts, positrons, were collided head on.

When the collision energy reached 3.105 billion electron volts there was, according to yesterday's joint announcement, a "sudden enormous increase" in the number of heavy particles produced. This indicated the production of a particle whoes mass was equivalent to that energy.

Such a particle would be three and a half times as heavy as the proton.

Existence Is Implied

At Brookhaven a proton beam with an energy of 30 billion electron volts, impinging on stationary protons, produced a large number of electron-positron pairs at 3.1 billion electron volts. This, too, implied the existence of such a particle. The fact that similar results emerged from such different experiments is seen as strong confirmation for the finding.

One of the chief surprises is the long life of the particle. Even though it decays on the average in 100 billionths of a billionth of a second, so heavy a particle would be expected to decay 1,000 times that fast.

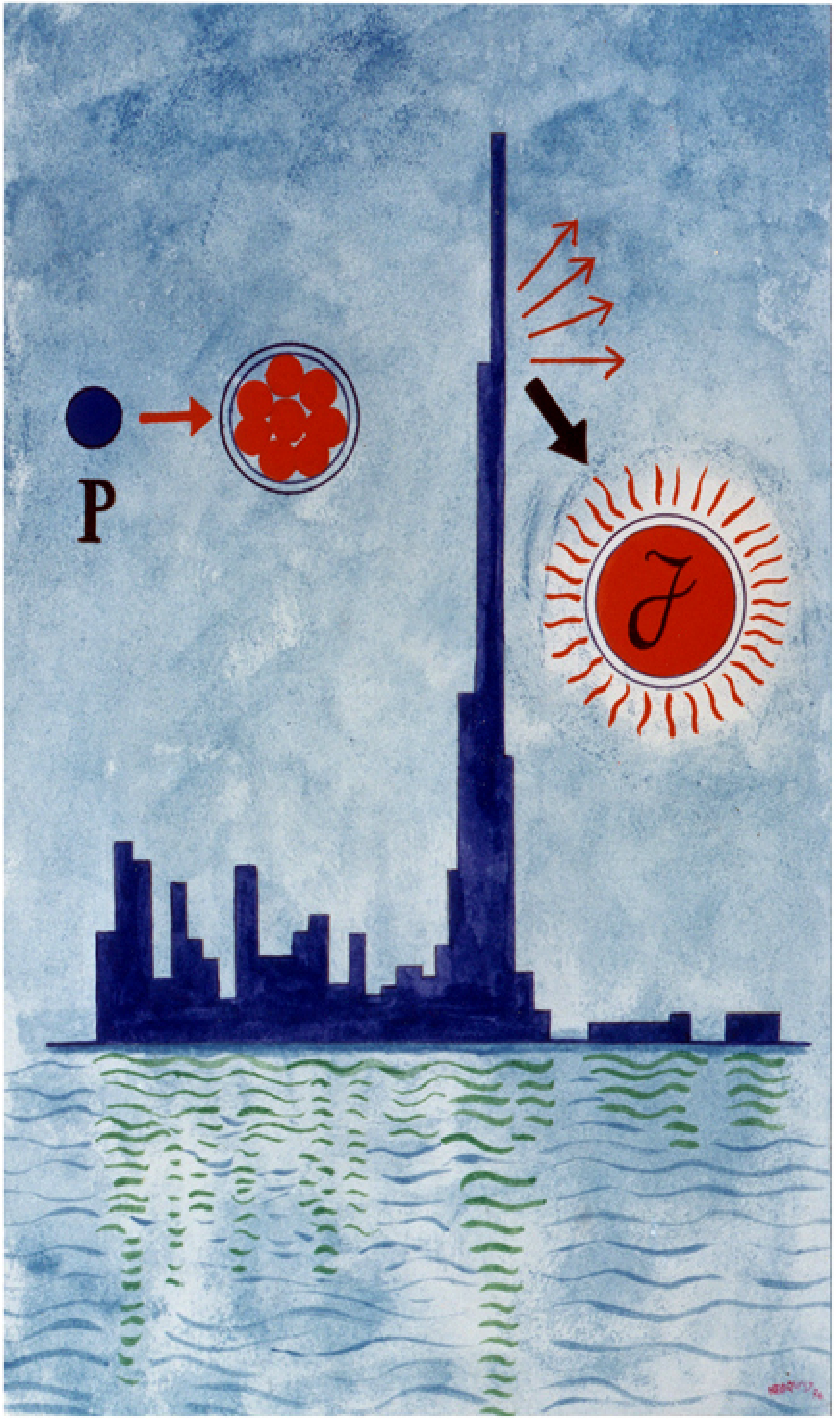
The findings are to be reported in the Dec. 2 issue of Physical Review Letters.

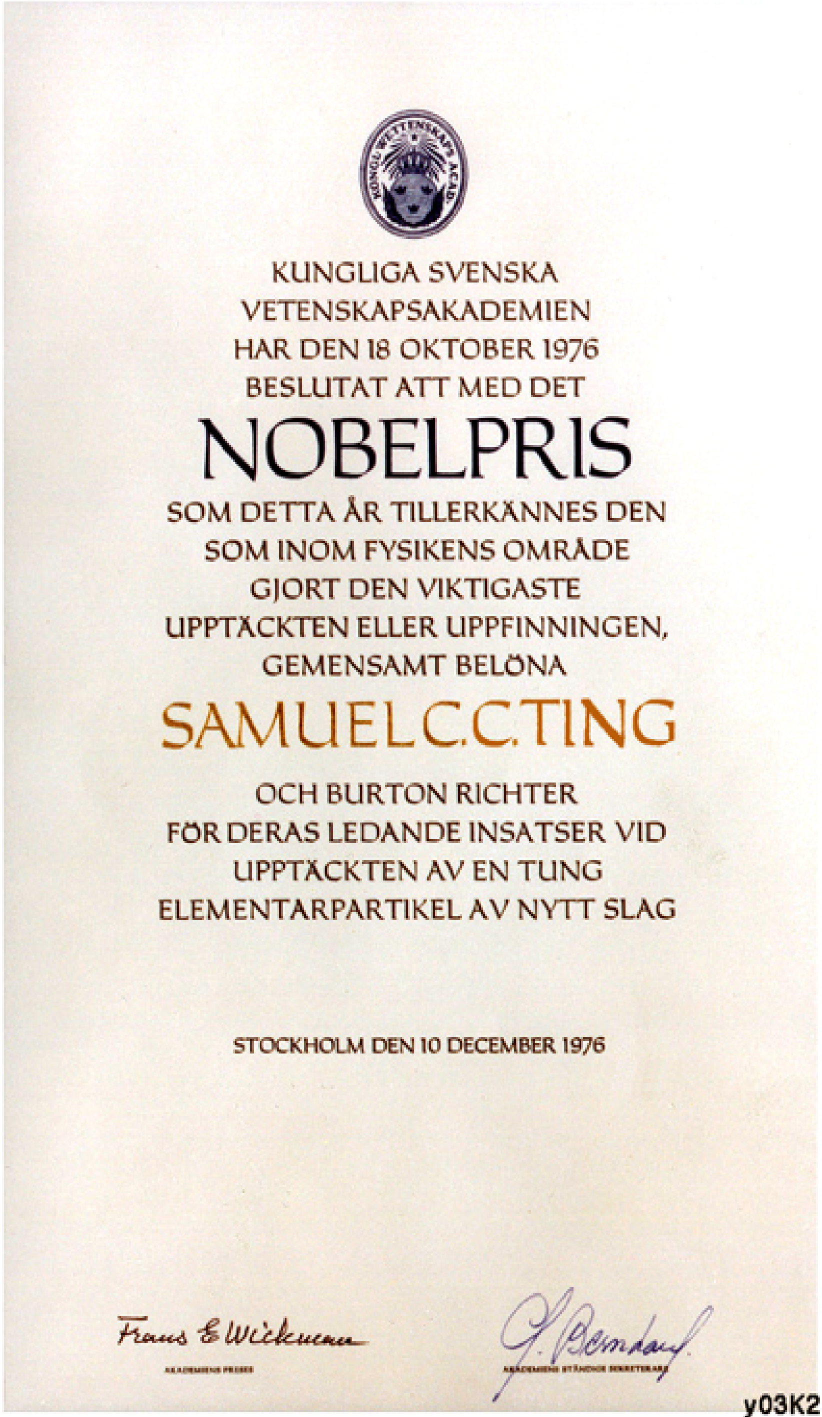
Participants at Brookhaven included Drs. U. J. Becher and Min Chen of M.I.T. and Y. Y. Lee of Brookhaven. At Palo Alto, they included Drs. Roy F. Schwitten and Rudolf R. Larsen of that laboratory and Drs William Chinowsky, Gerson Goldhaber and George H. Trilling of the Lawrence Berkeleay Laboratory of the University of California.

The idea that the weak force — that responsible for radioactive decay — must be transmitted by a particle of some sort derives from the knowledge that the other forces are expressed in this way. For the electromagnetic force, it is the photon — or light wave. For the nuclear force, it is the pi-meson. For gravity, is is the hypothetical gravition.

Because of vain attempts to find such a particle transmitting the weak force, it has been suspected that if is very heavy — more than 10 times the mass of the proton and three times the mass of the new particle.

The latter bears no electric charge and is believed to have the properties described by physicists as spin one and negative parity.





KUNGLIGA SVENSKA
VETENSKAPSAKADEMIEN
HAR DEN 18 OKTOBER 1976
BESLUTAT ATT MED DET

NOBELPRIS

SOM DETTA ÅR TILLERKÄNNES DEN
SOM INOM FYSIKENS OMRÅDE
GJORT DEN VIKTIGASTE
UPPTÄCKTEN ELLER UPPFINNINGEN,
GEMENSAMT BELÖNA

SAMUEL C.C. TING

OCH BURTON RICHTER
FÖR DERAS LEDANDE INSATSER VID
UPPTÄCKTEN AV EN TUNG
ELEMENTARPARTIKEL AV NYTT SLAG

STOCKHOLM DEN 10 DECEMBER 1976

Frans E Wickman
AKADEMIENS PRESES

G. Bernhard
AKADEMIENS STÄNDIGE SEKRETERARE

Lesson Two:

Always keep faith in yourself.

Do what you think is right.

Third Story:

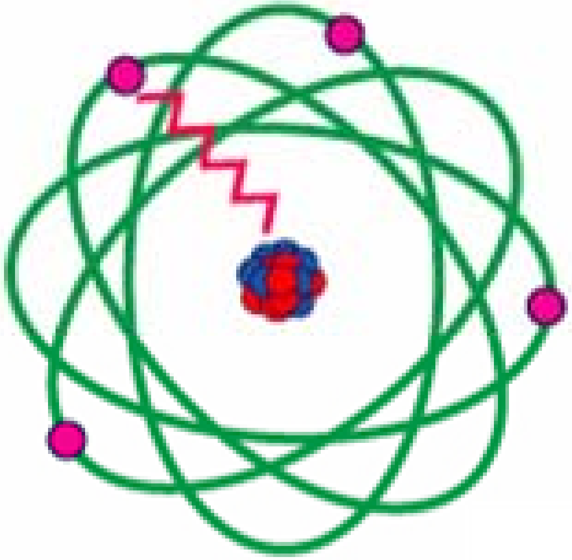
Discovery of Gluons

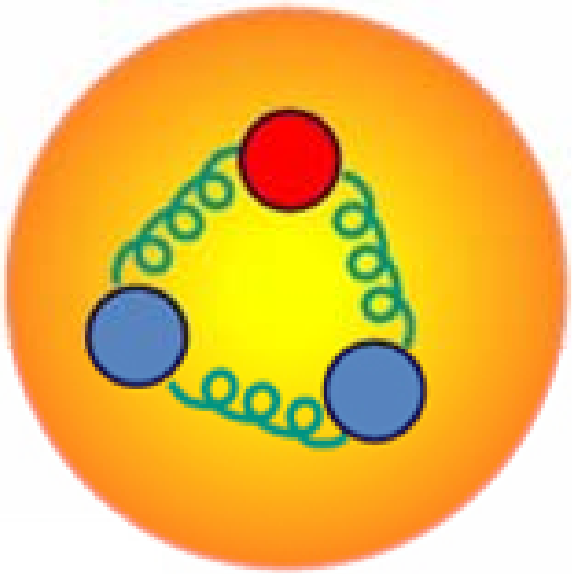
Photons

carriers of the force
in the atom (light)

Gluons

carriers of the force
between Quarks

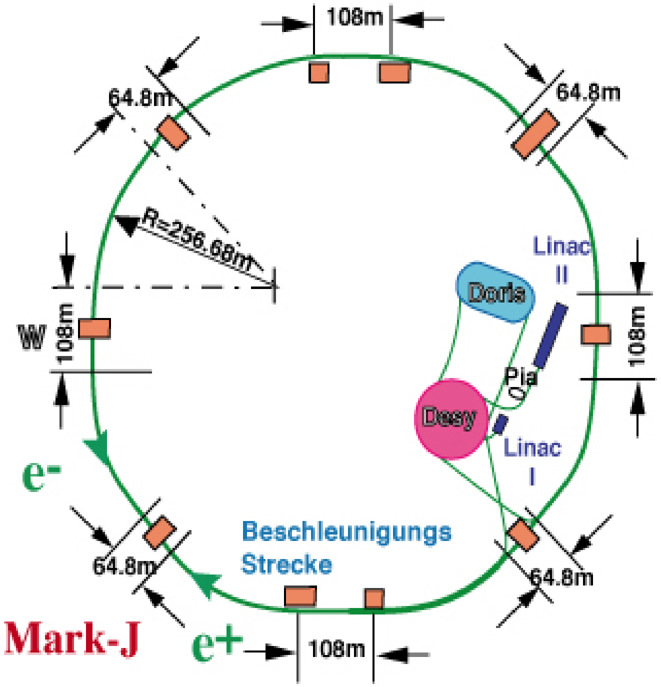


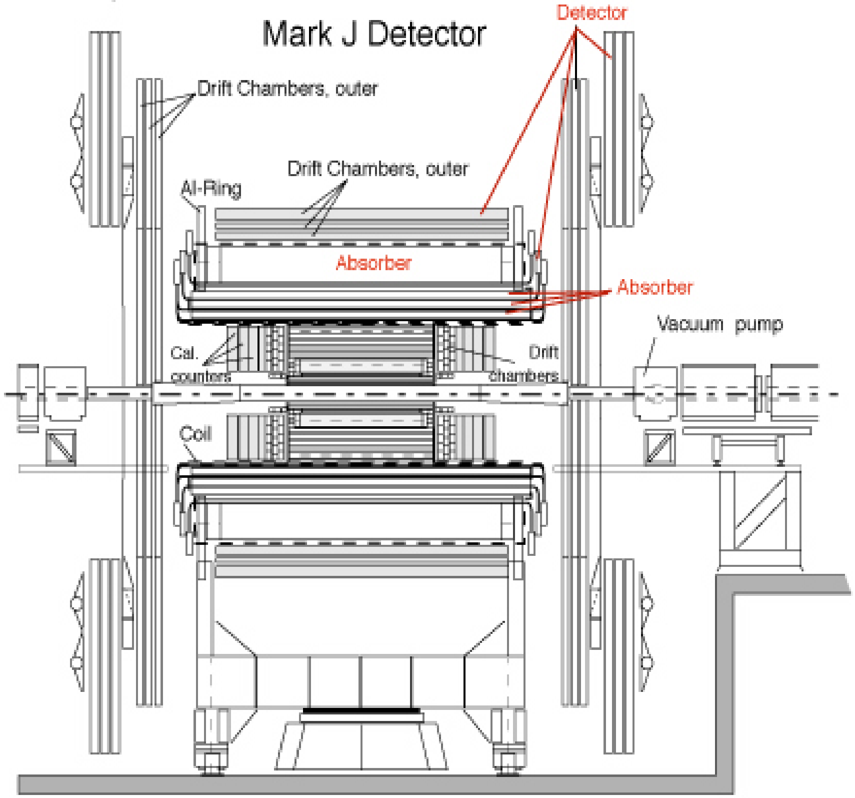


World's first large electron-positron collider

Hamburg Petra, 1978 - 1983

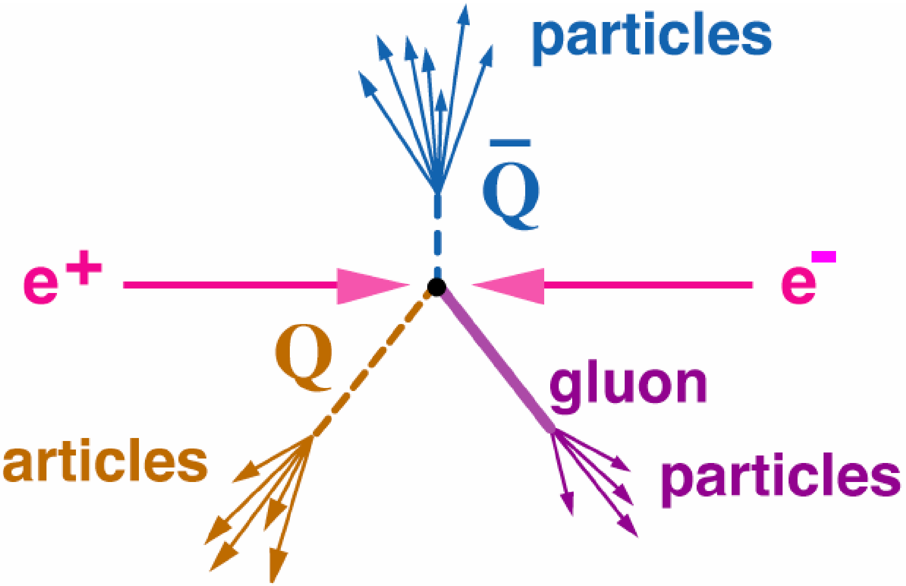
E = 46 BeV, ϕ = 7 km



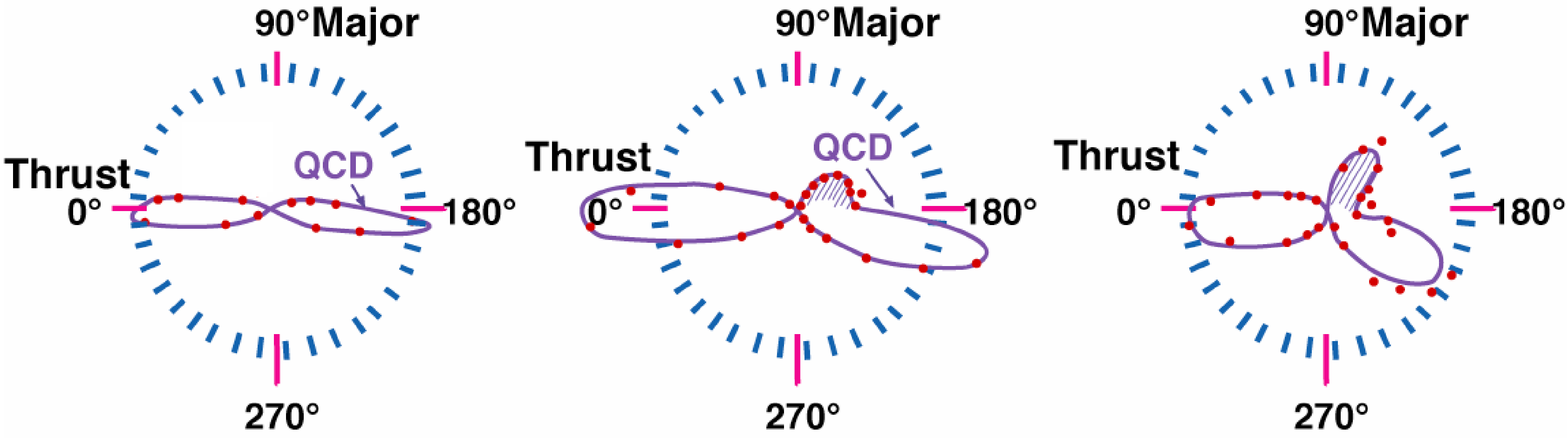


Radiation protection
Absorber
Physics
Discovery of Gluons

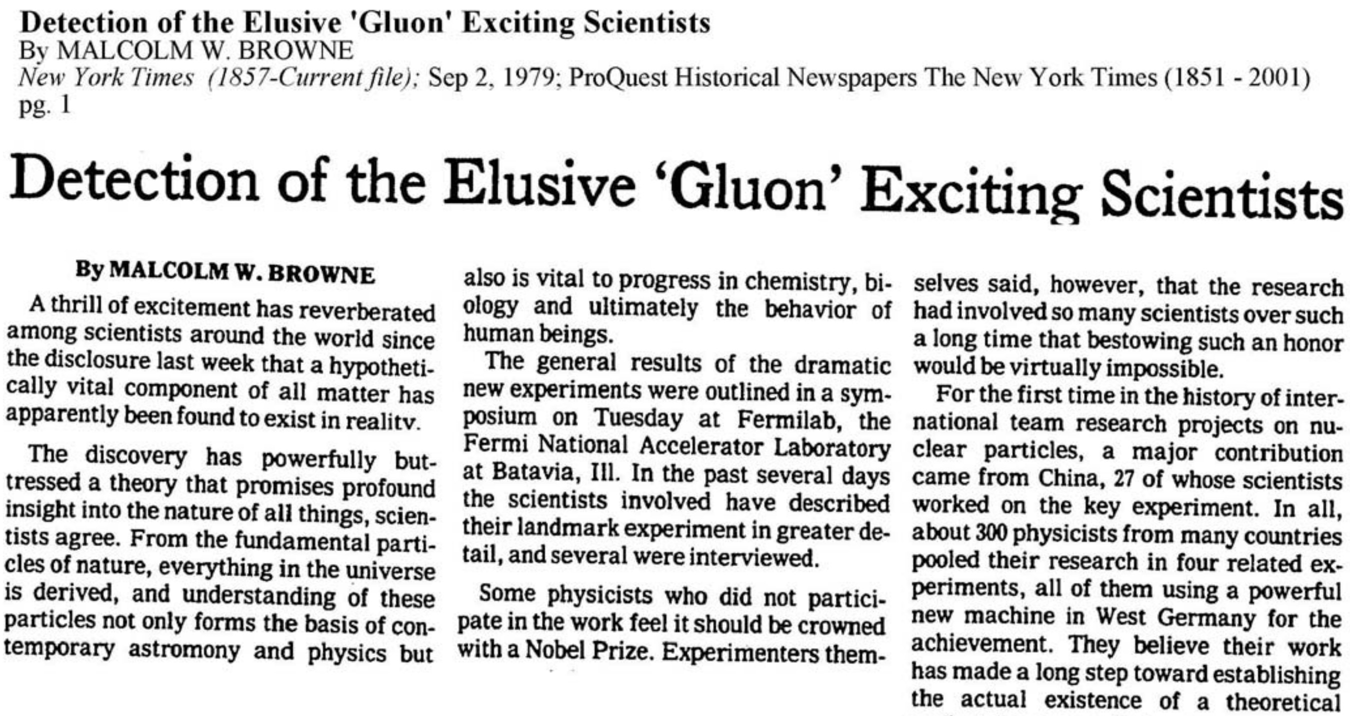
y685_0dcy0255



increasing Gluon Energy



The discovery of gluons
New York Times, Sept 2, 1979, page 1.



Detection of the Elusive 'Gluon' Exciting Scientists
By MALCOLM W. BROWNE
New York Times (1857-Current file); Sep 2, 1979; ProQuest Historical Newspapers The New York Times (1851 - 2001)
pg. 1

Detection of the Elusive 'Gluon' Exciting Scientists

By MALCOLM W. BROWNE

A thrill of excitement has reverberated among scientists around the world since the disclosure last week that a hypothetically vital component of all matter has apparently been found to exist in reality.

The discovery has powerfully buttressed a theory that promises profound insight into the nature of all things, scientists agree. From the fundamental particles of nature, everything in the universe is derived, and understanding of these particles not only forms the basis of contemporary astromony and physics but also is vital to progress in chemistry, biology and ultimately the behavior of human beings.

The general results of the dramatic new experiments were outlined in a symposium on Tuesday at Fermilab, the Fermi National Accelerator Laboratory at Batavia, Ill. In the past several days the scientists involved have described their landmark experiment in greater detail, and several were interviewed.

Some physicists who did not participate in the work feel it should be crowned with a Nobel Prize. Experimenters themselves said, however, that the research had involved so many scientists over such a long time that bestowing such an honor would be virtually impossible.

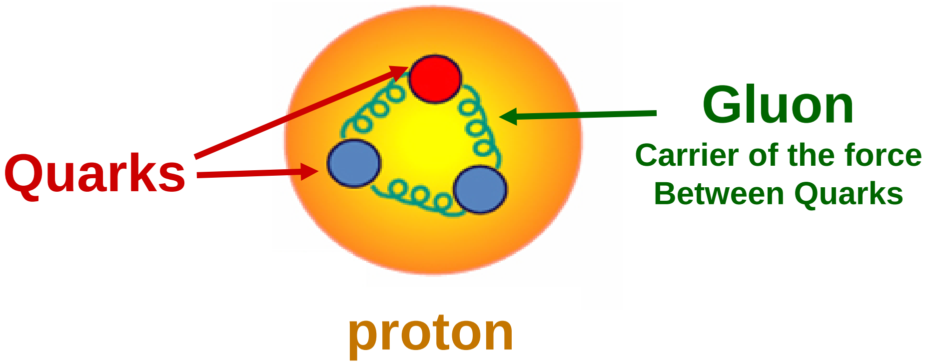
For the first time in the history of international team research projects on nuclear particles, a major contribution came from China, 27 of whose scientists worked on the key experiment. In all, about 300 physicists from many countries pooled their research in four related experiments, all of them using a powerful new machine in West Germany for the achievement. They believe their work has made a long step toward establishing the actual existence of a theoretical packet of energy called a gluon.

Team Leader From M.I.T.

If a fundamental theory of matter called quantum chromodynamics, or QCD, is correct, the gluon must exist, and if the scientists had failed to find it in their new experiment, much of the theoretical work in physics in the past decade would have been in serious doubt.

The leader of the 56-member team that produced the most dramatic results was Dr. Samuel C.C. Ting of the Massachusetts Institute of Technology, who shared the 1976 Nobel Prize in Physics with Bur-

Continued on Page 28, Column 1

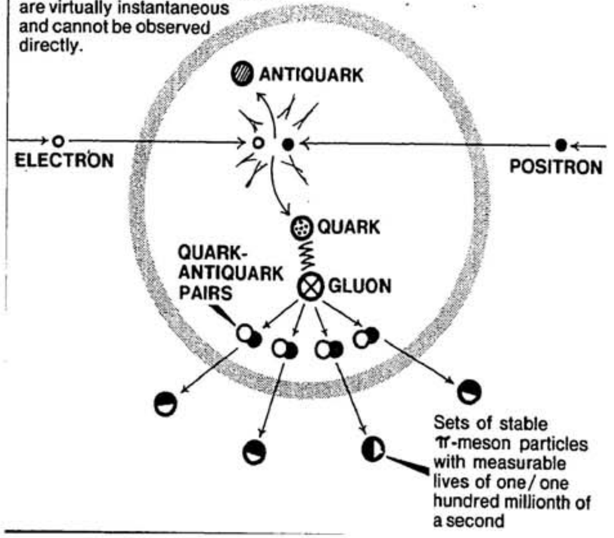


Detection of Elusive Energy Packet Called the 'Gluon' Is Exciting Scientists Worldwide

Continued From Page 1

Finding The Gluon

Events that occur within the circle are virtually instantaneous and cannot be observed directly.



Sets of stable π-meson particles with measurable lives of one/one hundred millionth of a second

ton Richter for their discovery of a nuclear particle called the J/Psi particle.

"Our latest experiment has not absolutely clinched the QCD theory," Dr. Ting said in a telephone interview from Europe, "but if we had not seen this evidence the theory would have been in trouble. As it is, every experiment of the last 10 years has supported QCD, and we've now reached the point that we believe it is probably correct."

An understanding of QCD requires a look at the history of man's study of the atom.

Growth of Theories

Until about the end of World War II, physicists believed the atom could be described by a rather simple model. Each atom was believed to contain a nucleus made up of presumably indivisible heavy particles — positively charged protons and particles of equal size but without electric charge, known as neutrons. Around this nucleus whirled a layered cloud of negatively charged light particles called electrons, the number of which, in a simple, uncombined element, matched the number of protons in the nucleus.

The discovery that an atomic nucleus is made up of protons and neutrons was made by banging nuclei apart, using fast-flying particles or atoms as hammers. The impacts cast off debris — fragments of the original nuclei — whose flights could be studied through the tracks they left on photographic plates, through microscopic streaks as they passed through bubble chambers and through other devices.

To increase the precision of their experiments, scientists over the years have needed ever more powerful tools to cause harder collisions and break fragments and particles into ever smaller bits. As technology improved, the accelerators they used grew increasingly powerful, but instead of confirming traditional theories, surprises began to occur with disquieting frequency. The protons, neutrons and other heavy particles once thought to be the ultimate building blocks of nature were themselves breaking up or transforming into many puzzling particles never previously suspected.

Mysteries were proliferating faster than answers. A longstanding joke among physicists has it that nuclear particles are like onions — you strip off one layer and there's always another one underneath.

"Who knows, there may really be no end to it," Dr. Leon M. Lederman, director of Fermilab, remarked recently.

Physicists have so far catalogued more than 100 different kinds of nuclear particles. The confusion has been further complicated by awareness that four fundamental forces governing all of nature are very imperfectly understood.

The existence of gravity and the electromagnetic force have both been long known, but two other forces were needed to understand how an atomic nucleus behaves.

One of these, dubbed the "strong force," was defined as the force that keeps nuclear particles from merely drifting apart, since gravity is far too weak to hold them together. Another force, the "weak force," would account for the radioactive decay of certain atoms.

In the 1960's, science found a possible way out of the confusion through a theory, developed by Murray Gell-Mann of the California Institute of Technology, that postulated the existence of a fundamental particle named the "quark."

Dr. Gell-Mann found a logical way of grouping the proliferation of particles into species and subspecies and postulated that the massive particles, such as protons and neutrons, actually consist of triplets or pairs of different kinds of quarks bound together.

If this were correct, all matter could be broadly grouped into two major classes — the light, dimensionless particles called leptons (electrons, for example), and the more massive quarks, which are believed to occupy definite amounts of space.

But reality could not be explained by the existence of just one kind of quark.

Experiments of recent years led to the grouping of different quarks in terms of at least five "flavors" and three "colors." Such names are merely conveniences, and have no more meaning than numbers.

Origin of Chromodynamics

The differentiation by "color" refers to the fact that quarks seem to behave as if they carried three different kinds of charge — not electrical charge, but something analogous to it. The study of the "color" of both matter and antimatter suggested the name "chromodynamics," which has nothing to do with real, visible color.

Complicating the problem of sorting out particles was the discovery that for every kind of matter there is a corresponding form of antimatter. The major particles making up antimatter have the opposite charge of its corresponding form of matter. When matter and antimatter are combined, they annihilate each other, to be instantly reborn as new forms of matter and energy.

The mechanisms by which these strange changes occur must be driven by forces of various kinds, but a complete understanding of the nature of all forces has defied science.

It is relatively easy to predict how matter will respond when subjected to the familiar gravitational and electromagnetic forces, but how are these or any other forces carried from one thing to another to cause their observed effects?

In the case of electromagnetic force, the problem was solved earlier in this century. The carrier of electromagnetic force was shown to be the photon, a massless packet of vibrating energy that makes up such forms of radiation as visible light, X-rays, radio waves and so on. But what about gravity and the newly discovered strong and weak forces?

The way gravity is conveyed has proved by far the most difficult to explain, partly because gravity is much weaker than other forces, and must be studied on a cosmic scale rather than an atomic scale.

Research has moved faster in the investigation of the weak force, and in the past few years its distinctive carrier has been fairly well established as the elusive and barely detectable neutrino. Neutrinos have sometimes been called the "ghost particle" because of their ability to pass through any matter almost unimpeded.

That left the strong force as the best remaining target for research having a realistic hope of success. The trouble was that to find the carrier of the strong force would involve *smashing particles together* at energies beyond the scope of the most powerful existing accelerators.

German Accelerator Used

Finally, an accelerator equal to the task was built by West Germany at the Deutsche Elektronen-Synchrotron (DESY) complex at Hamburg. The accelerator, called PETRA, was brought up to its full power in recent months, and scientists from the world's leading physics laboratories began organizing teams to work there.

Their target was the particle presumed by the chromodynamic theory to exist as a carrier of the strong force, which holds atomic nuclei together. They had whimsically named this particle the "gluon" because of its supposed ability to hold together the groups of quarks making up stable particles, which in turn are bound together in the atomic nucleus.

There was no hope of directly detecting, or "seeing," the gluon, according to theory, because it could exist as a separate entity for only an instant of time too short to measure. Actually, no one has yet "seen" a single, uncombined quark, and scientists are undecided as to whether such a "free" quark could exist.

But despite the impossibility of "seeing" a gluon, it can leave an indirectly detectable signature. Once formed, the gluon would be expected to transform itself into a cascade of pairs of quarks, converting its energy into matter to create the quarks. These quark pairs would combine to form relatively stable particles, whose behavior would reveal how they had come into being. The daughter particles born from this train of transformations, called pi mesons, live for only about one one-hundred-millionth of a second, but that is long enough to tell the tale.

For the gluon research, the PETRA accelerator was gradually throttled up to near its maximum energy, and when the machine had reached a power of about 30 billion electron volts, the experiments began.

In one direction, electrons were whipped around at increasing speed, while their antimatter equivalent, positrons, were accelerated in the opposite direction. The huge energy of the machine was pumped into these tiny particles, to be combined in their occasional head-on collisions.

Chromodynamics had predicted that the pi mesons streaming out of these collisions as the result of the birth and transformation of gluons should group themselves in three jets moving at slightly different angles. If only two jets of pi mesons were detected coming from each collision, the entire chromodynamic theory would be in serious doubt.

When the experiment was actually performed the third jet of pi mesons "clearly and unambiguously" appeared in the sensitive recording equipment of the teams led by Dr. Ting and others. The gluon had been found.

"Of course, we'll never actually see the gluon itself," Fermilab's Dr. Lederman said. "The nature of such particles can only be learned by inference, like the nature of a ball or boomerang that you cannot see but which is being thrown between two boats. You study the angles and speeds at which the boats recoil after each throw, and from that you deduce the properties of the object itself and how the boats interact with it and each other."

人民日报
NMIN RIBAO
1979年9月5日　星期三
农历己未年七月十四　第11380号

贯彻三中全会方针农业生产迅速发展

村秋后市场旺　购销安排不容缓

国供销社主任会议研究措施，要求广开门路扩大货源

京九月四日电　新
道：正在北京举行
、自治区供销社主
列举大量材料说明，
中全会以后，全国农
展很快，农村市场
有过的购销两旺的
，今年秋后农村市
多年少见的旺盛局

农民出售了大量农副产品，手中有了钱，就要购买工业品和其他各种消费品。因此，今年农村销售市场也十分活跃。上半年农村商品零售额比去年同期增长百分之十一点六，其中消费资料增长百分之十三点八。代表们用大量事实说明，今年农民对消费品的需求已经发生了新的变化：一，买吃的减少了，

们热诚希望轻纺等工业部门努力增加生产，供应更多更好适合农村需要的商品。轻纺工业的原料百分之六十在农村，全国各地供销社要大力组织收购，积极支持轻纺工业的发展。代表们指出：安排好秋后旺季市场，具有十分重要的政治意义。农村商业职工要克服依赖和等待思想，广开门路扩大货源。

丁肇中教授领导的实验小组发现胶子

这种新粒子发现引起全世界科技界极大兴趣

我科学院高能物理研究所唐孝威等二十多位科学工作者参加这项实验研究

新华社北京九月四日电　引起全世界科学技术界极大兴趣的新粒子——胶子的发现，是由著名美籍物理学家丁肇中教授领导的高能物理实验小组，最近在西德汉堡的一台高能加速器上找到实验证据的。中国科学院高能物理研究所唐孝威等二十多位科学工作者也参加了这项实验研究工作。

我国科学工作者收到了丁肇中小组发表的一篇论文，这篇论文公布了这种胶子存在的实验数据。

刚从丁肇中教授领导的小组归来的中国科学院高能物理研究所科学工作者在一次学术报告会上说，丁肇中教授领导的小组自一九七八年十一月在西德汉堡电子同步加速器中心，利用一台目前世界上能量最高的加速正负电子的对撞机寻找新的粒子，并研究高能物理的新现象。他们经过半年多的努力，在对一种称为“喷注”现象进行分析的过程中，在质心能量从二百七十四亿到三百一十六亿电子伏特的范围内，找到了四百四十六个喷注事例，并对这些事例的能流分布进行了大量的分析计算后，首次找到了胶子存在的实验证据。这一重要发现对于加深人类对物质微观结构的认识，具有重大意义。

物质是由分子组成的，分子是由原子组成的，原子是由电子和原子核组成的。原子核是由质子和中子组成的。质子、中子这一类粒子统称为强子，它们是由层子组成的。近十年来，科学家们曾经预言，层子之间的很强的相互作用力，是通过一种称为胶子的新粒子传递的。它们象胶水一样，以很强的力量，把层子和层子“粘”在一起。但是，胶子是否真的存在，一直是个悬而未决的问题。过去，实验上已经证实了五种层子的存在。但是，一直没有找到胶子存在的实验证据。丁肇中教授领导的小组进行的实验，首次回答了这个问题，从实验上证实了胶子的存在，从而引起了全世界高能物理学界极大的兴趣，这也是对高能物理领域中目前流行的强作用的理论一个有力的支持。

丁肇中教授领导的小组除有我国科学工作者参加外，还有美国麻省理工学院、西德电子同步加速器中心、西德亚琛大学物理研究所、荷兰核子和高能物理研究所的科学家参加。

在这台加速器上工作的其他实验小组也陆续找到了胶子存在的实验证据。

《参考消息》1979年9月11日转载《纽约时

【本刊讯】美国《纽约时报》九月二日登载马尔科姆·布朗的一篇文章，题目是《难以捉摸的“胶子”的发现使科学家们激动》，摘译如下：

自从上周宣布显然发现了原来假设的一切物质的一个极其重要的组成部分实际存在以来，在世界科学家中回荡着一片激动。

科学家们一致认为，这一发现强有力地支持了关于有可能深入了解万物性质的理论。宇宙中的一切都是从自然基本粒子衍生出来的。对这些粒子的了解不仅形成当代天文学和物理学的基础，而且对化学、生物学的进展以及最终对人类的行为的进步也是必不可少的。

没有参加这项工作的一些物理学家觉得，它应该获得诺贝尔奖金。

二十七名中国科学家参加了这次主要的实验，在有关核粒子的国际合作研究项目史上，这是第一次，也是中国的一大贡献。来自许多国家的总共大约三百名物理学家分四个有关的实验联合进行研究。

得到最惹人注目结果的五十六人研究小组组长是麻省理工学院的塞缪尔·C·C·（即丁肇中——本刊注）博士，他与里克特因发现一种称为丁／ＰＳＩ粒子的核粒子而分享了一九七六年物理学诺贝尔奖金。

丁博士说：“我们的最新实验还没有绝对证实量子色动力学理论。但是，如果我们没有看到这个证据的话，那么这个理论就会有麻烦了。事实上，近十年来的每一个实验都支持了这个理论。我们现在已经到了这个地步：可以说我们相信它大概是正确的”。

最后一点，胜任这次任务的一台加速器是西德在汉堡修建的德意志电子同步加速器中心的一台加速器。

这台称为“佩特拉”的加速器，近几个月里被开到最大功率工作。

他们的目标是色动力学理论所假设存在的作为强相互作用力载体的粒子。这种粒子使原子核保持在一起。

由于这种粒子具有假设的能使夸克群保持在一起组成稳定的粒子的能力，科学家们古怪地给这个

Lesson Three:

Be prepared for surprises.

Fourth Story: Large International Scientific Collaborations

L3 Collaboration

Aachen
Amsterdam
Ann Arbor
Annecy
Baltimore
Basel
Baton Rouge
Beijing
Berlin
Bologna
Bombay
Boston
Bucharest
Budapest
Cambridge
Florence
Geneva
Hamburg
Hefei
Helsinki
Korea
Lausanne
Los Alamos
Lyon
Madrid
Milan
Moscow
Naples
Nicosia
Nijmegen
Oak Ridge
Pasadena
Perugia
Pittsburgh
Princeton
Rome
St.Petersburg
San Diego
Santiago
Shanghai
Sofia
Taiwan
Tuscaloosa
West Lafayette
Zeuthen
Zurich

L3项目参加人员

唐孝威　陈和生　陈国明　陈　刚　杨长根　戴铁生
胡国安　宫竹芳　金炳年　李　澄　刘振安　陆文文
吕雨生　马文淦　宓　泳　蔡旭东　尤建明　钱剑明
裴益敬　周建峰　孙腊珍　童国梁　王建春　汪晓莲
王忠民　吴守庠　郁忠强　许咨宗　杨保忠　李　群
姚学毅　叶竞波　曾　英　张子平　周　冰　周　元
朱国义　朱人元　李培俊　亓曾笃　廖晶莹　汪兆明
庄红林　何景棠　吴义根　吴荣久　毛裕芳　王继华
杨海军　周广静　杨康树　李晓光　张志杰　曾吉阳
安　琪　宝建中　崔行天　崔晓英　李焕铁　范世骐
顾　创　郭景坤　何重蕃　马基茂　任忠良　任大宁
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沈长铨　武淑兰　过雅南　陈　昌　徐建国　董　岚
杨　民　杨晓峰　张守宇

The World is Made of Pointlike Particles:

Quarks

(u, d, s, c, b, t, …)

Leptons

(electron, Muon, Tau, Neutrino, …)

y120b

Experimental Questions

How many types of electrons are there ?

How large are the electrons ?

Can electrons be divided into smaller particles ?

y121

Experimental Questions

How many quarks are there ?

u, d, s, c, b, t, …

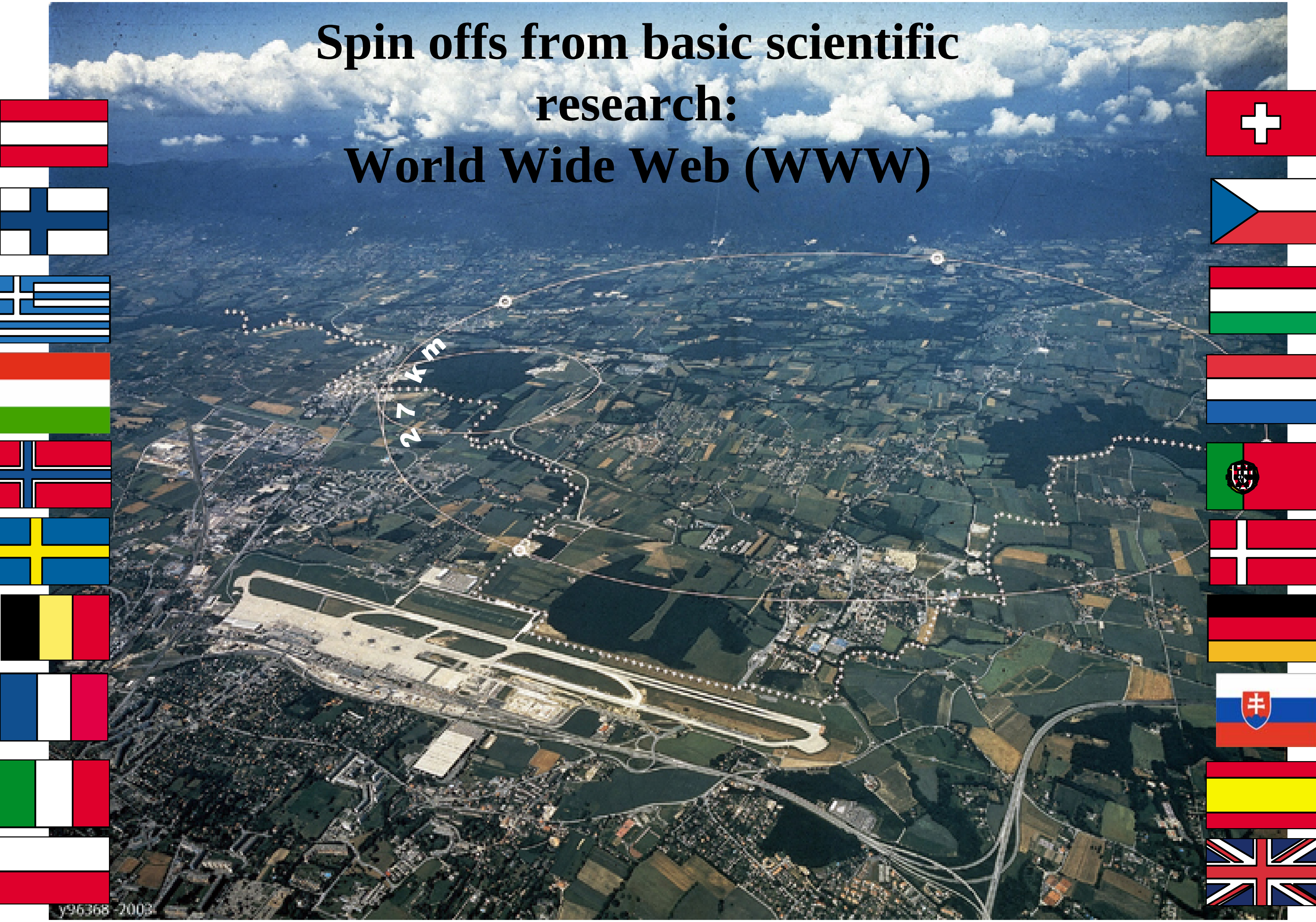
How large are the quarks?

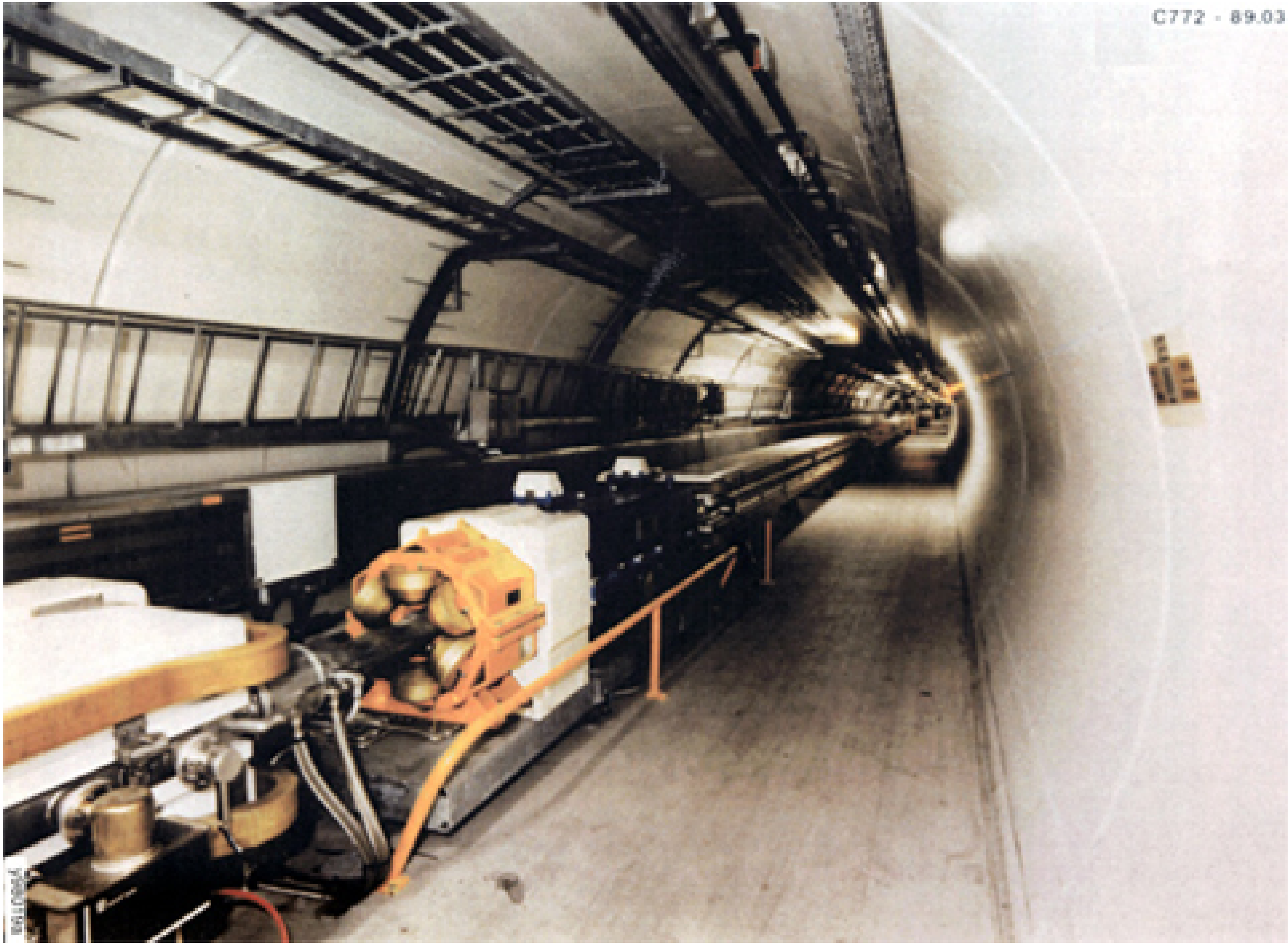
Can quarks be divided into smaller particles ?

y122

The L3 experiment at the 27 km Large Electron Positron Collider (LEP) at the European Organization for Nuclear Research (CERN) in Geneva

Spin offs from basic scientific research:
World Wide Web (WWW)





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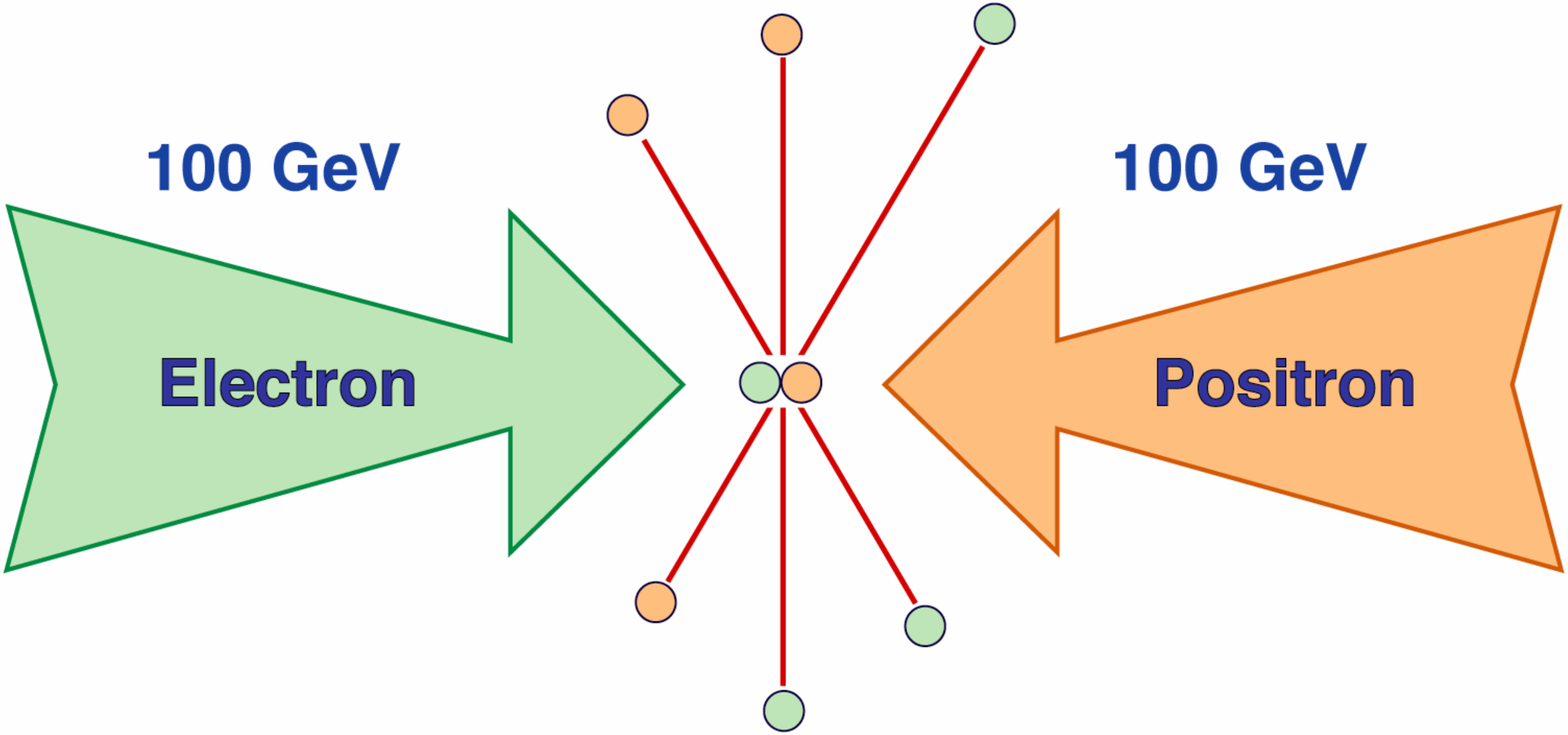
LEP

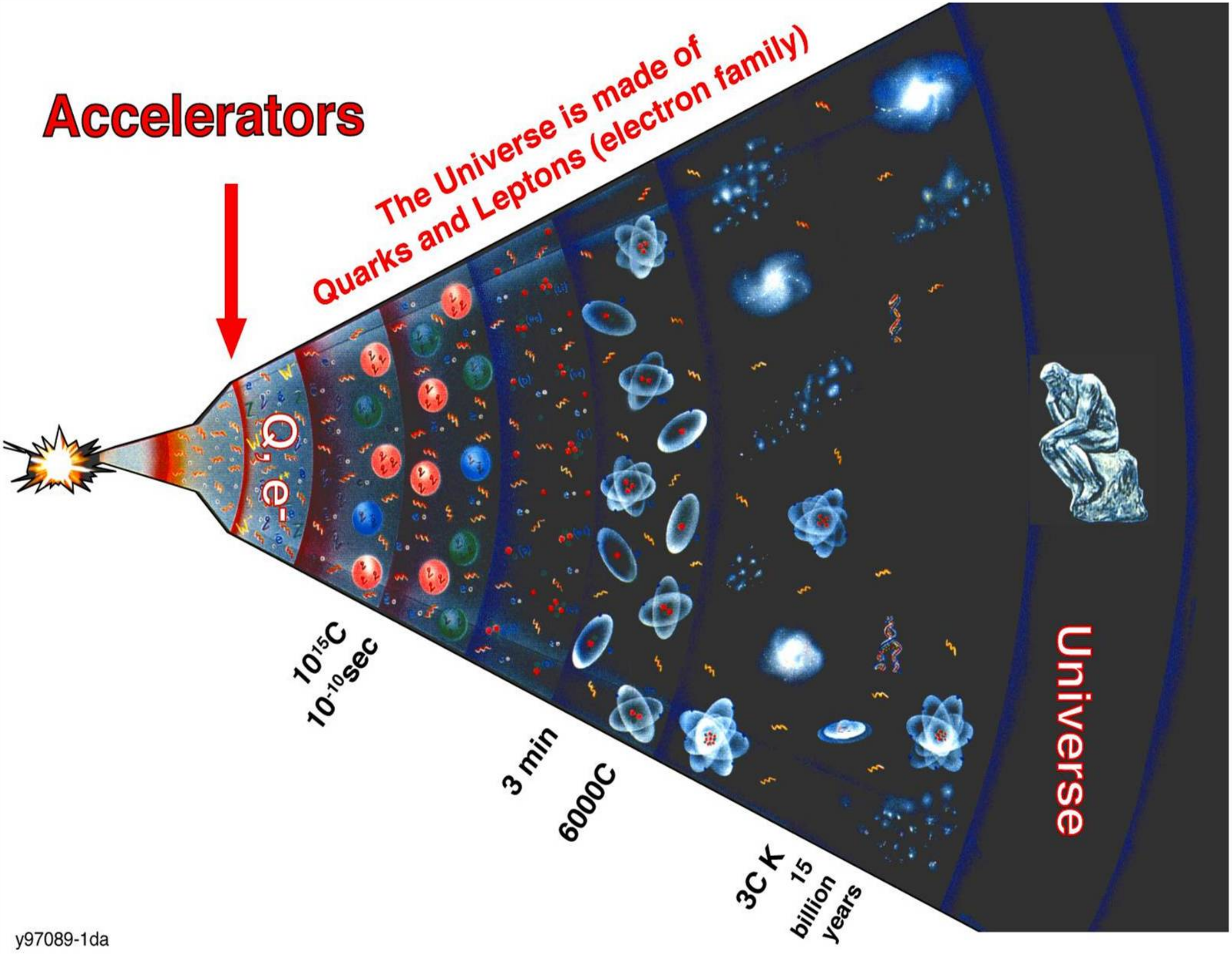


Temperature : 400 billion * surface of sun

First 0.00000000000000000001 seconds of the Universe

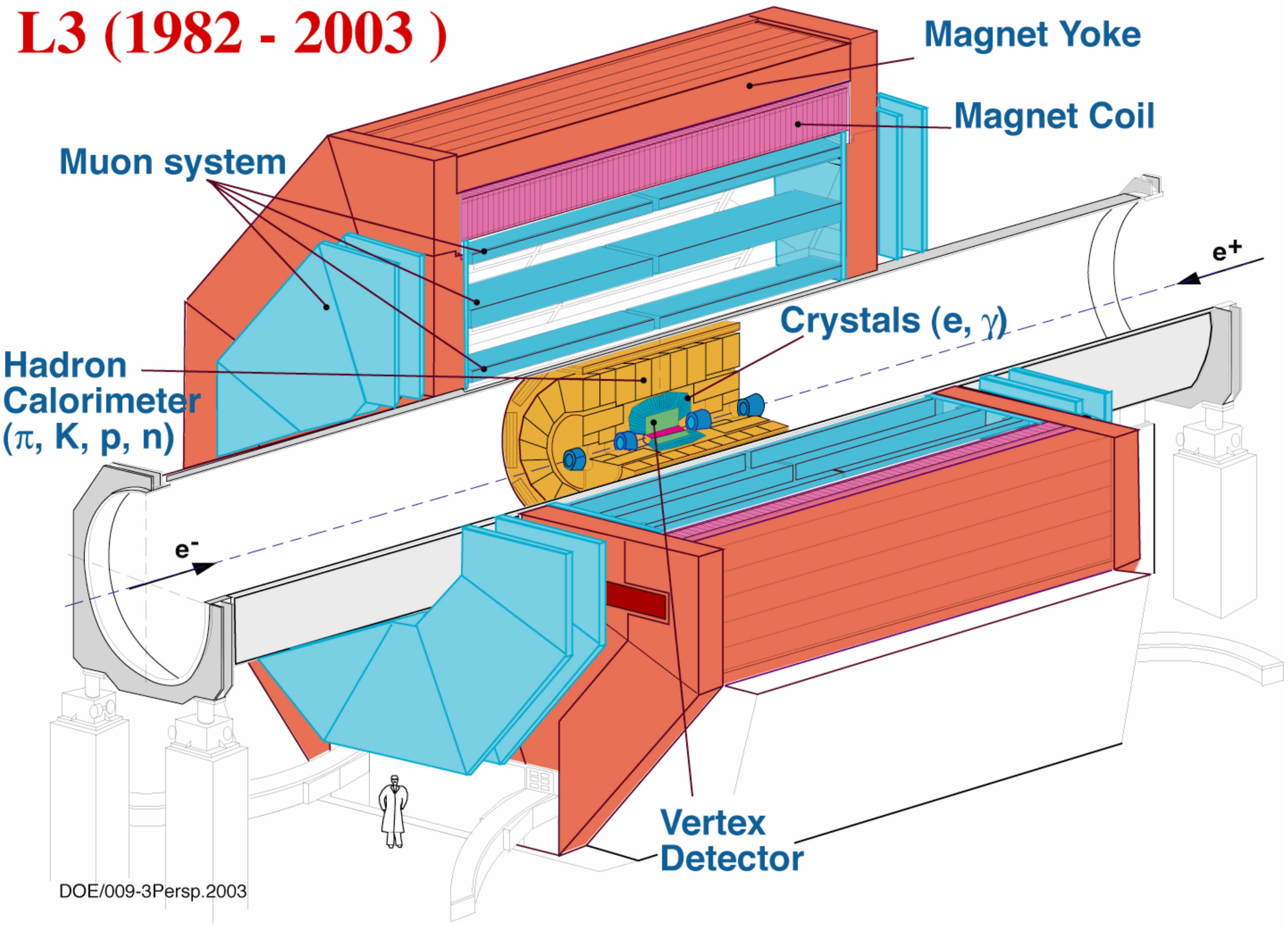
y94017a

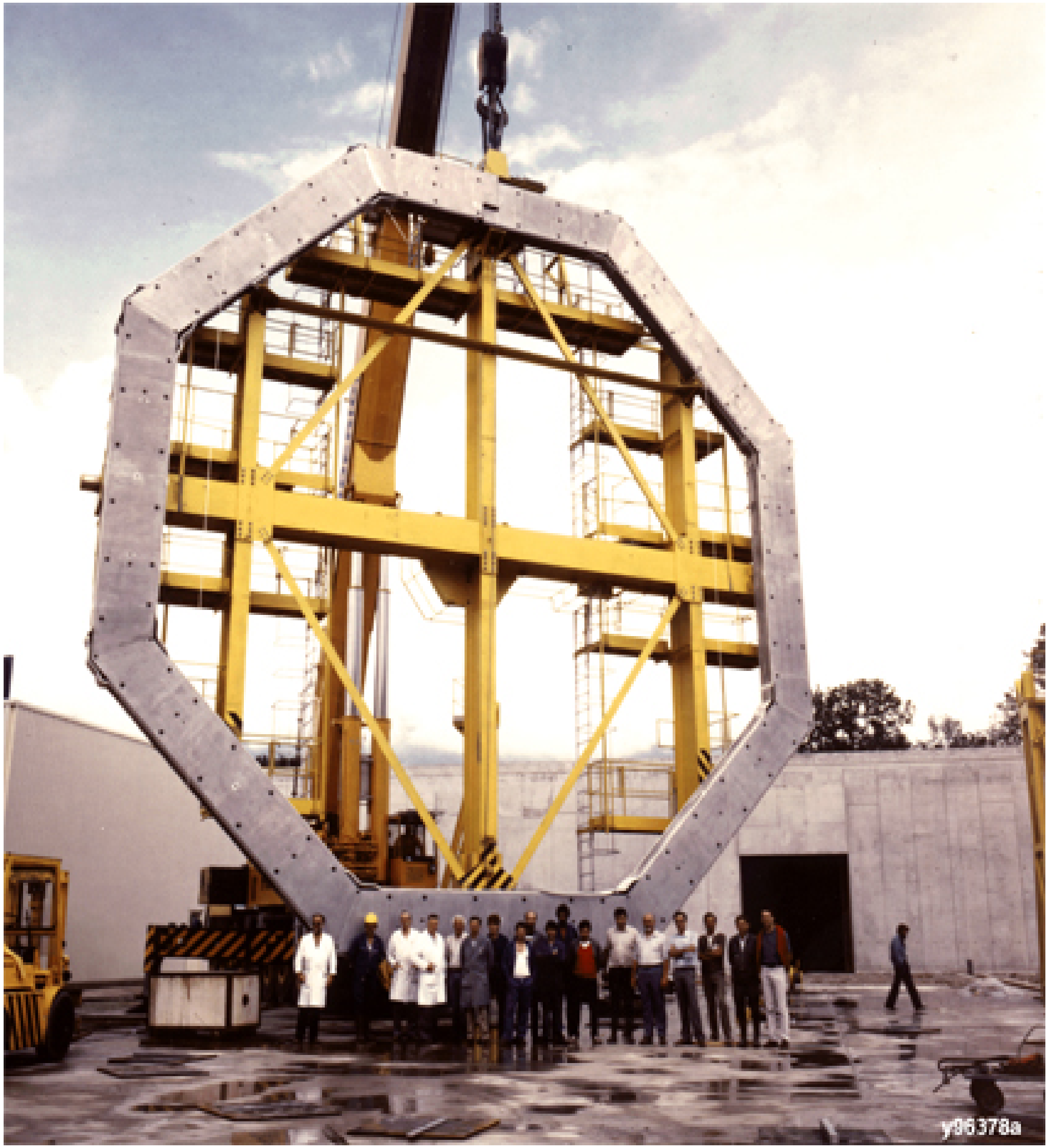
Accelerators



The Universe is made of Quarks and Leptons (electron family)

L3 (1982 - 2003)


Magnet Yoke
Magnet Coil
Muon system
Crystals (e, γ)
e+
Hadron
Calorimeter
(π, K, p, n)
e-
Vertex
Detector
DOE/009-3Persp.2003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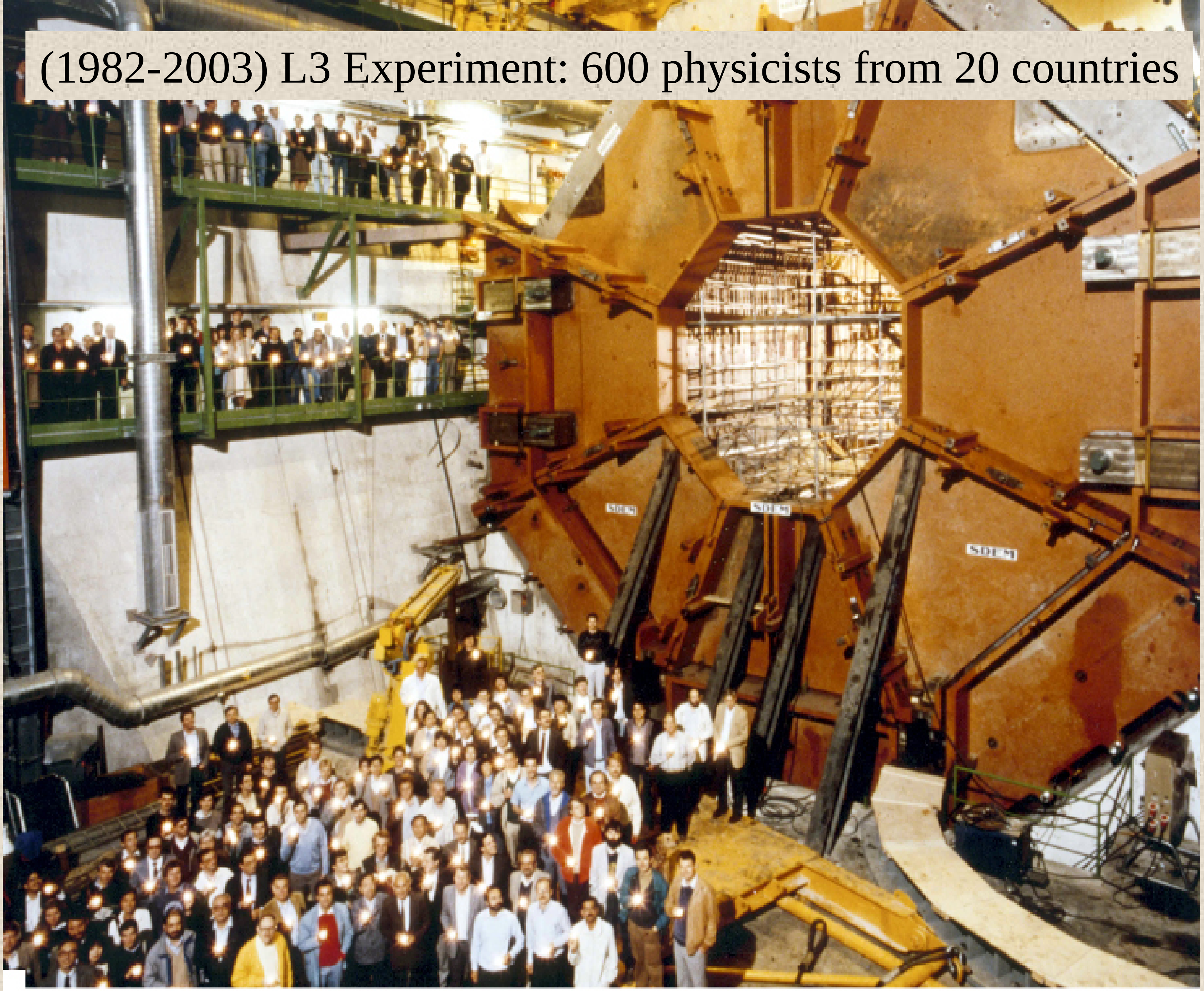
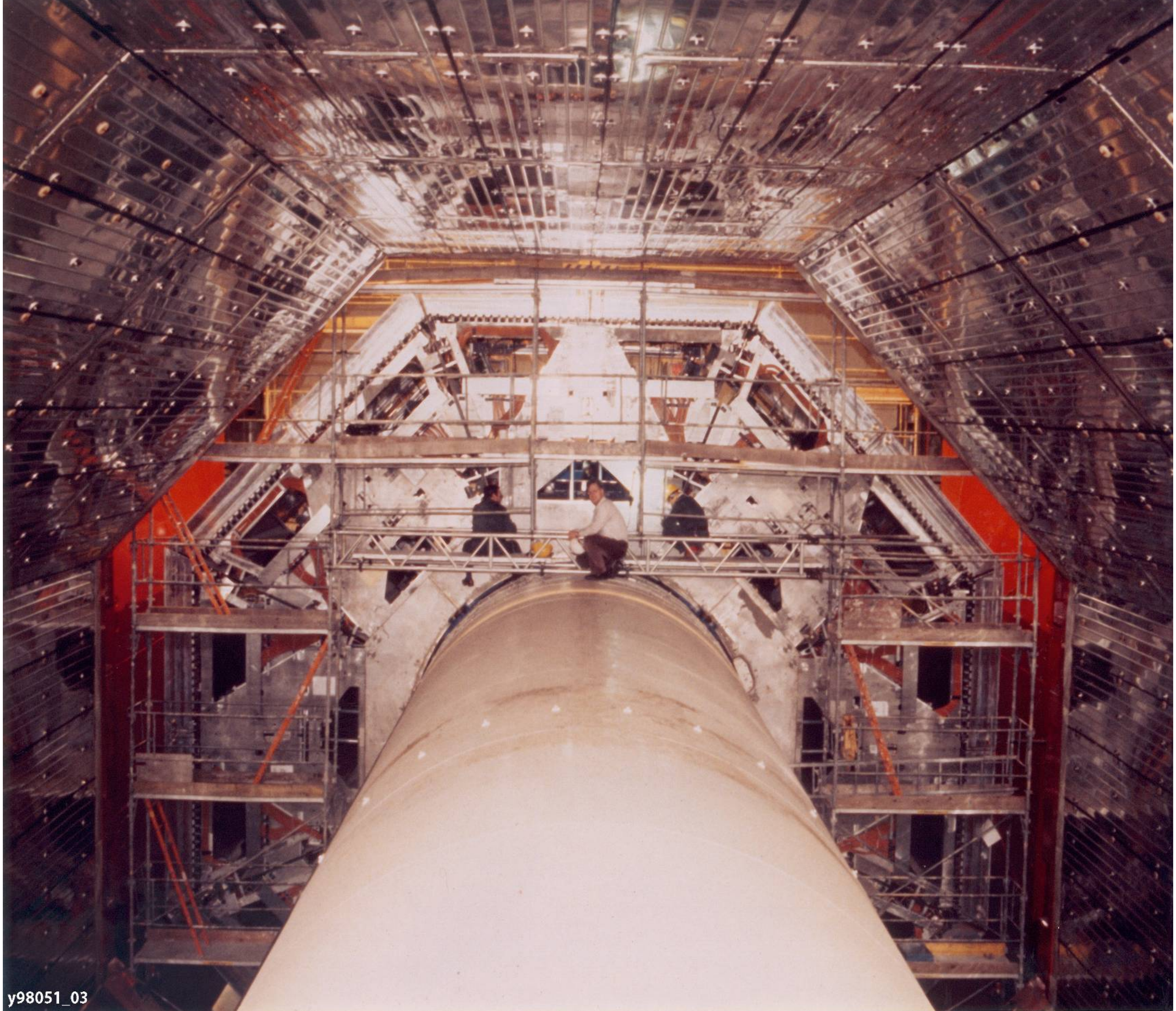
(1982-2003) L3 Experiment: 600 physicists from 20 countries





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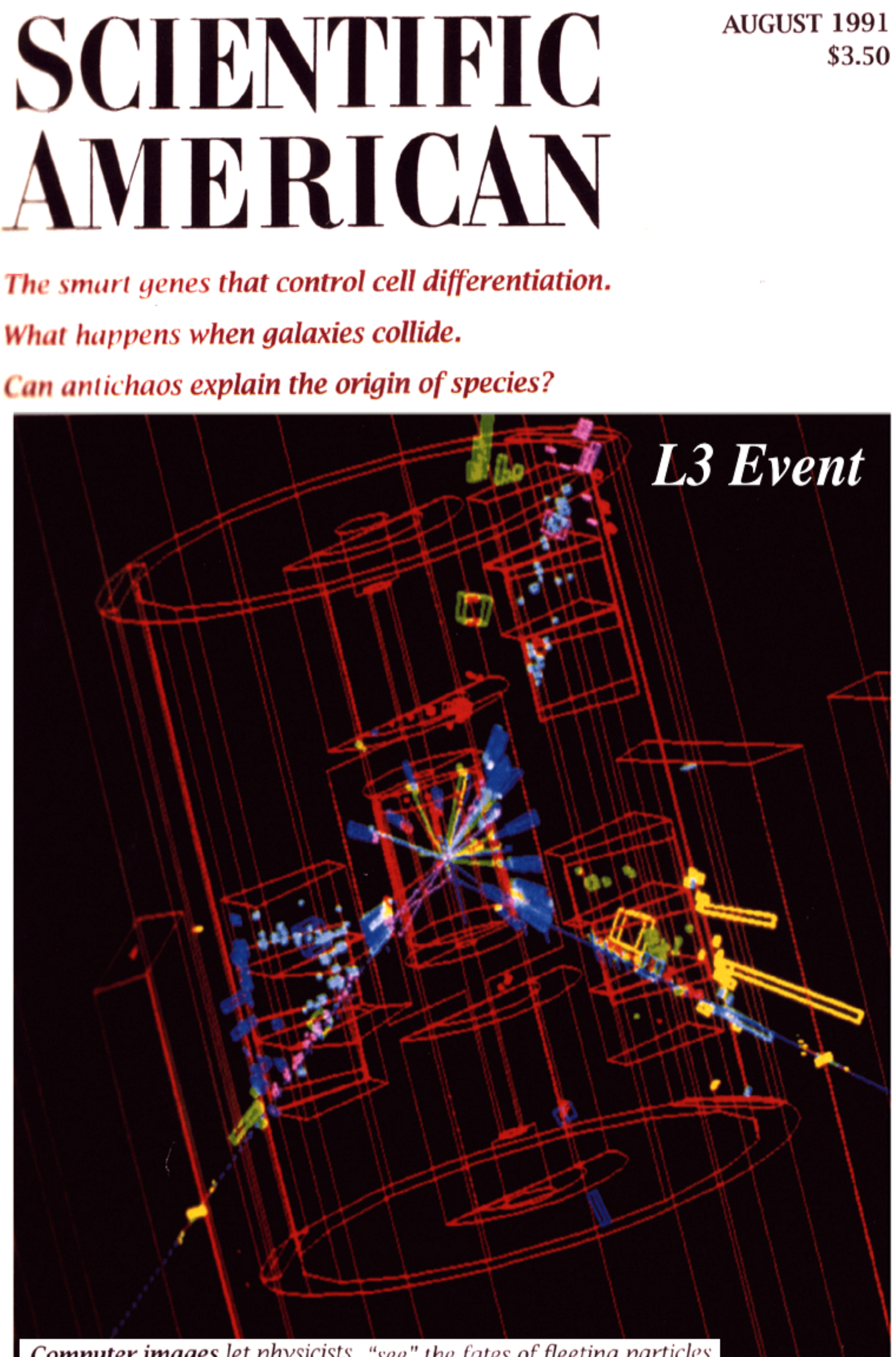


SCIENTIFIC AMERICAN

AUGUST 1991
$3.50

The smart genes that control cell differentiation.
What happens when galaxies collide.
Can antichaos explain the origin of species?

L3 Event

***Computer images** let physicists "see" the fates of fleeting particles*

L3 Results:

In the universe, there are only:

1) 3 kind of electrons **(e, μ, τ)**

2) 6 kind of Quarks

3) Electrons and Quarks have no size

Radius of e, μ, τ: $R_l < 10^{-17}$ cm

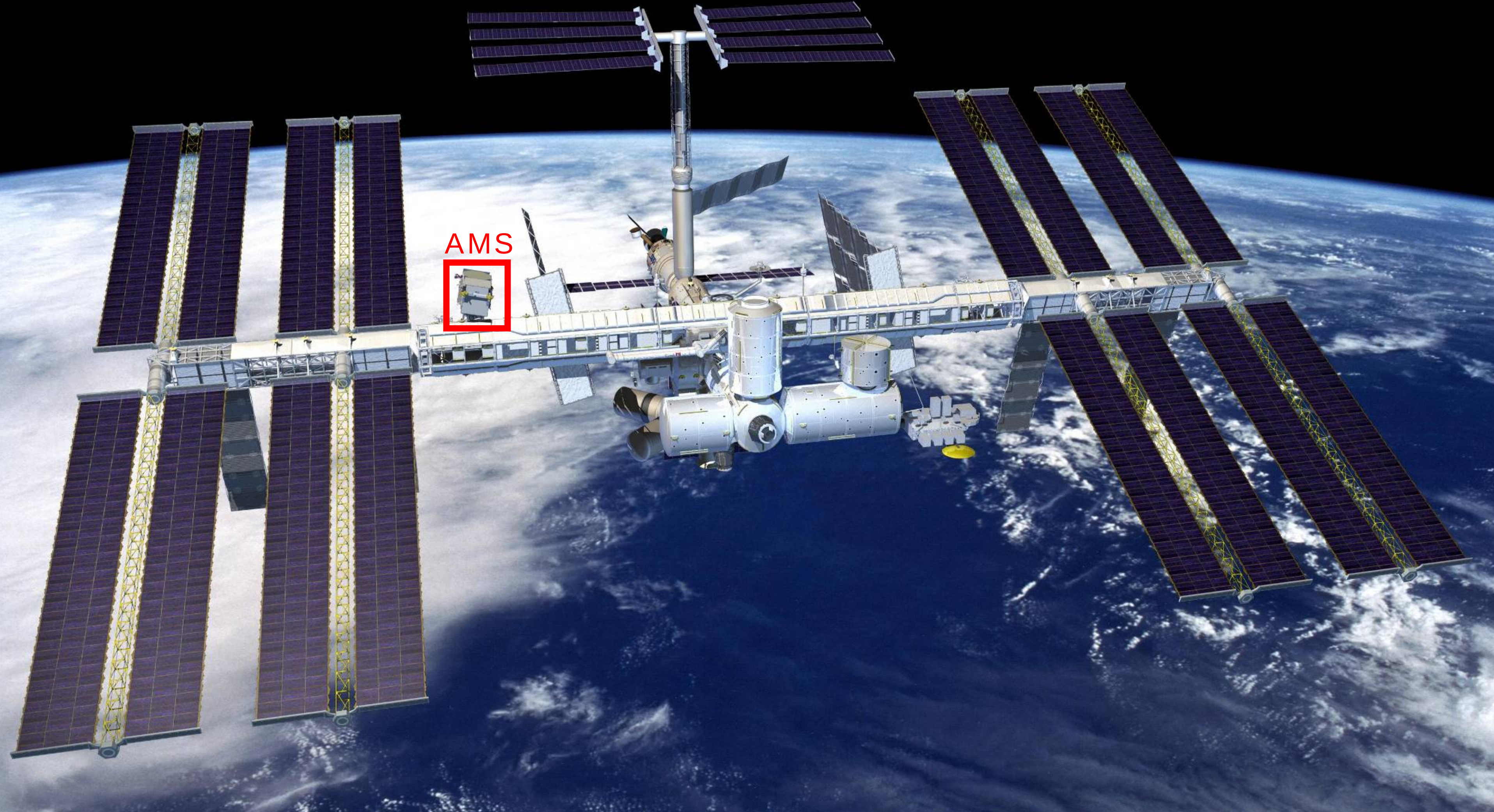
Radius of Quarks: $R_Q < 10^{-17}$ cm

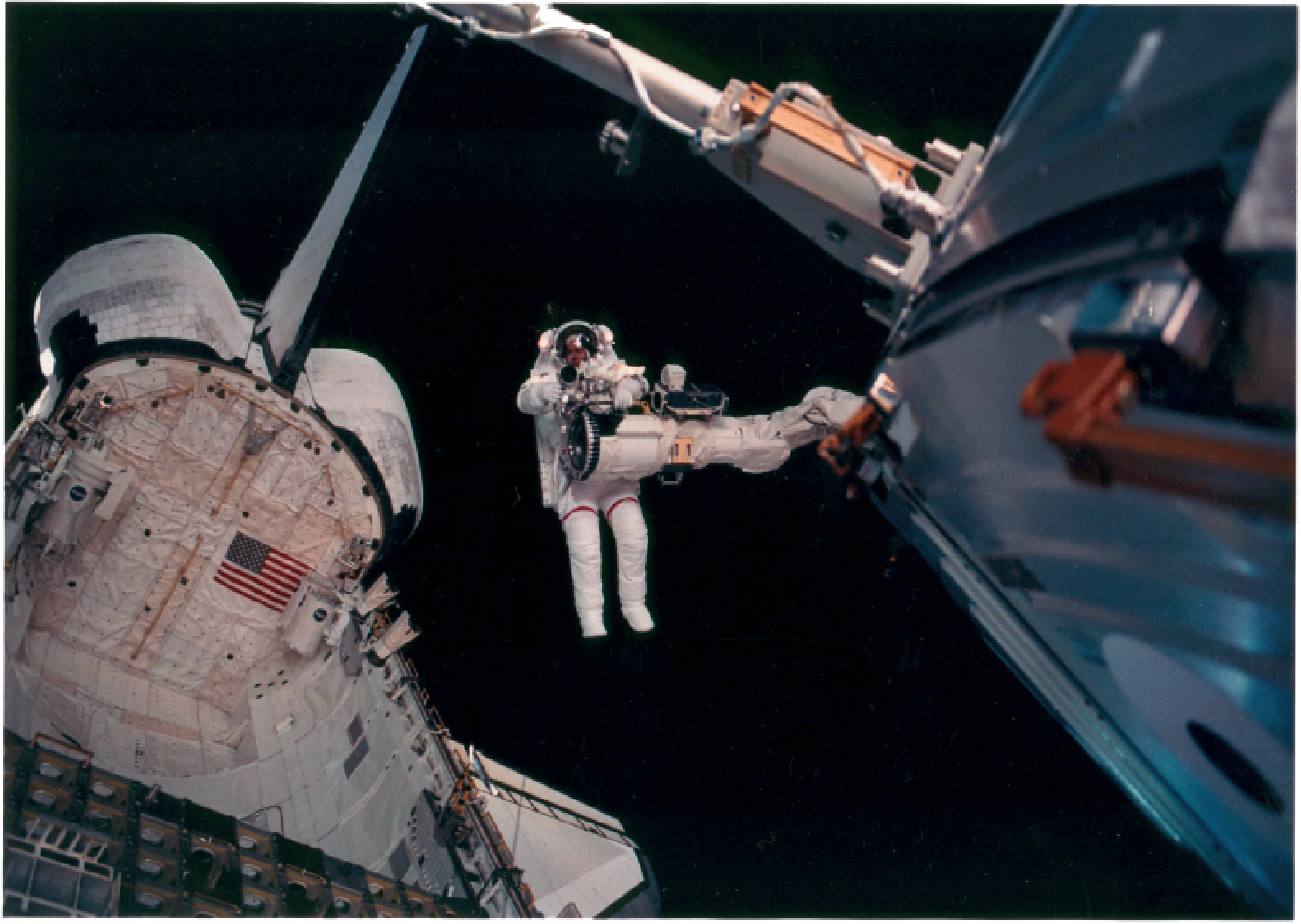
Lesson Four:

In science, the fundamental ideas are simple.

Fifth Story:

The Alpha Magnetic Spectrometer Experiment





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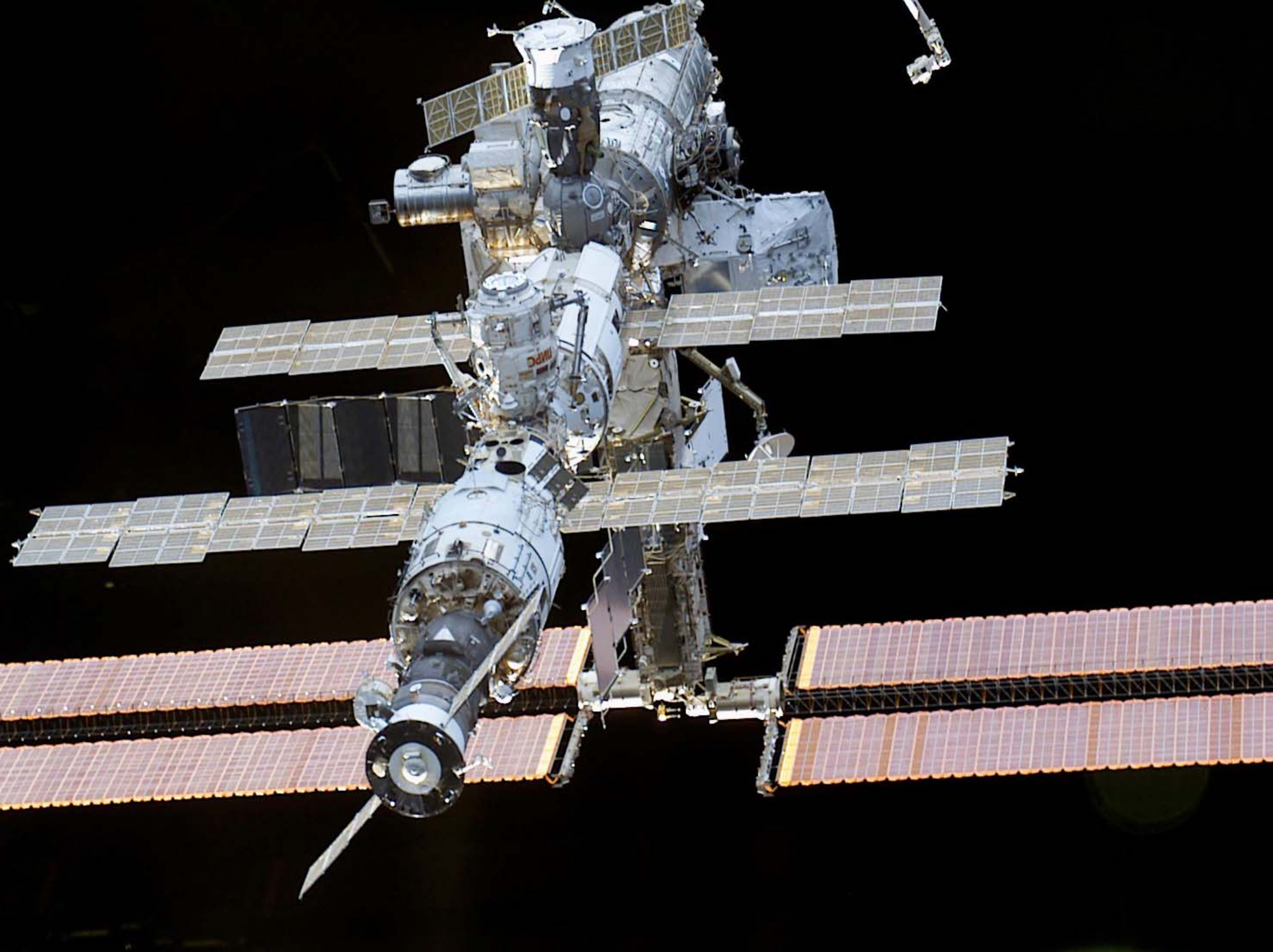
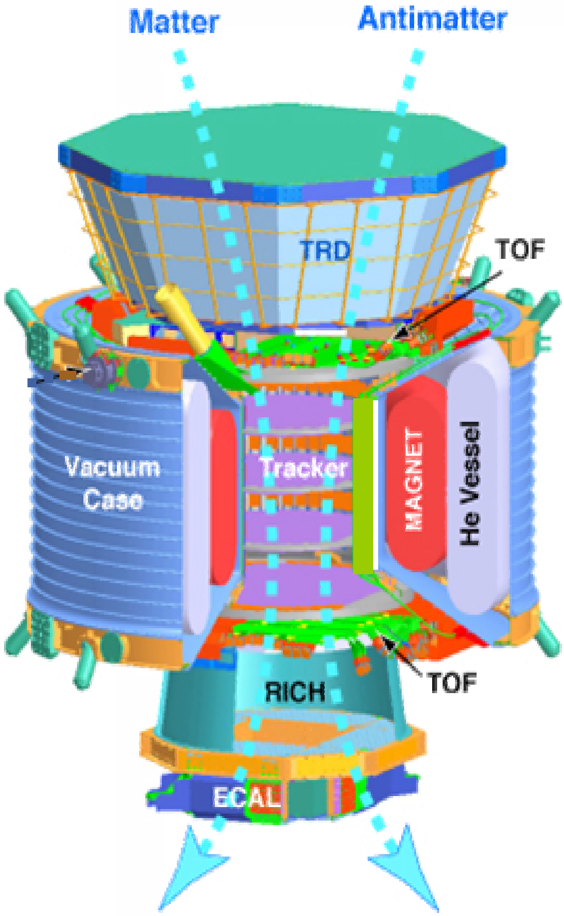
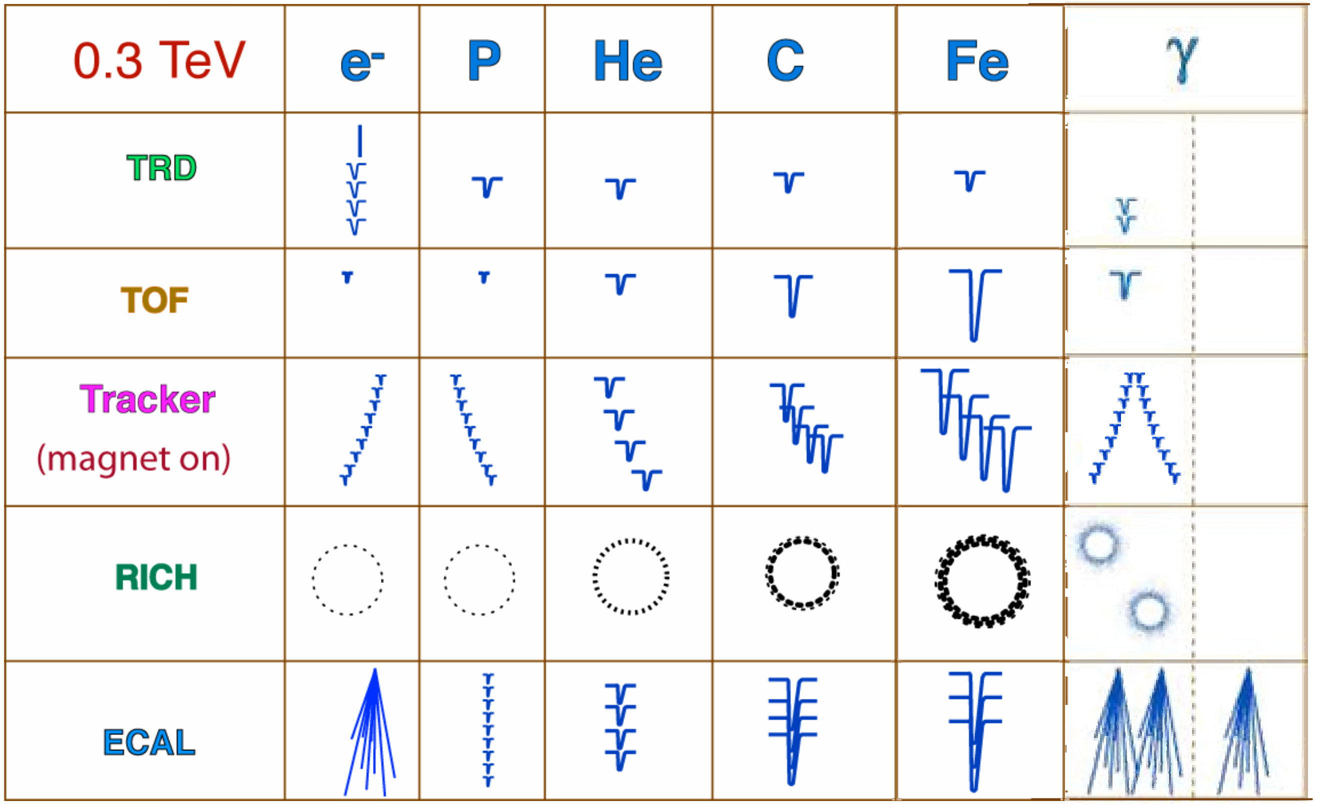


AMS: A TeV Magnetic Spectrometer in Space (3m x 3m x 3m, 7t)

The AMS detector has been under construction for 10 years.

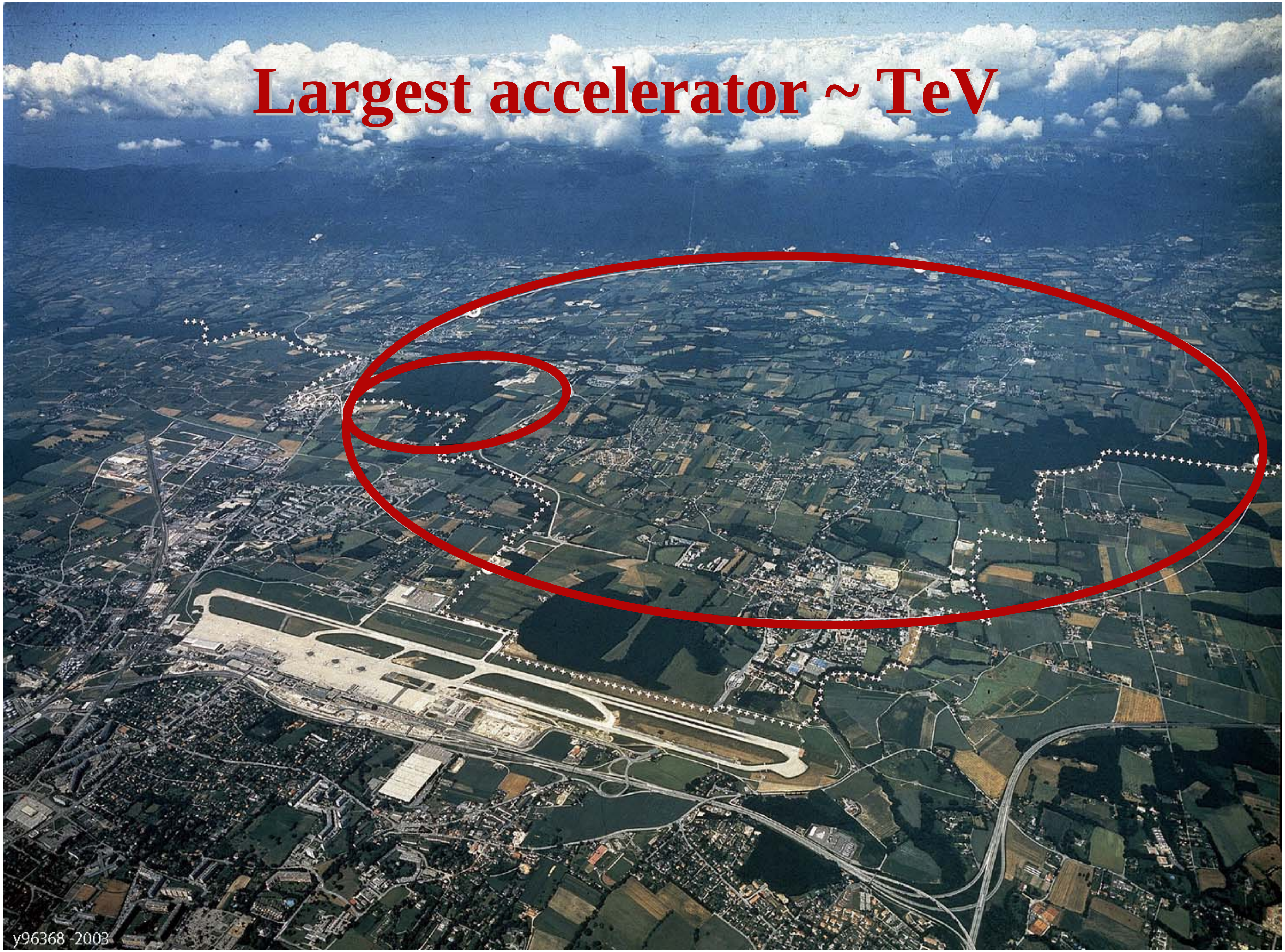


300,000 channels of electronics $\Delta t = 100$ ps, $\Delta x = 10\mu m$

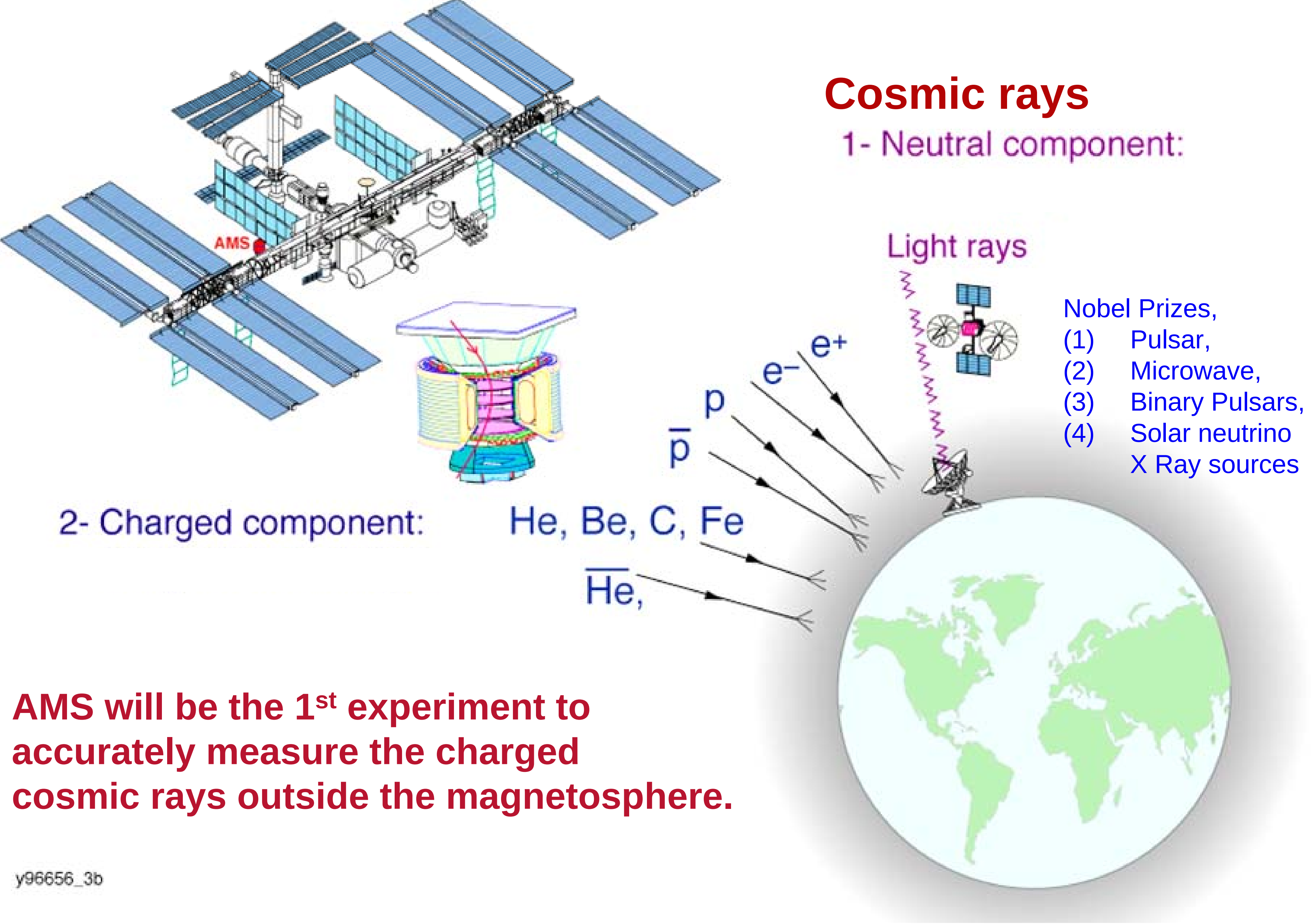


0.3 TeV	e⁻	P	He	C	Fe	γ
TRD						
TOF						
Tracker (magnet on)						
RICH						
ECAL						

Largest accelerator ~ TeV



Cosmic rays



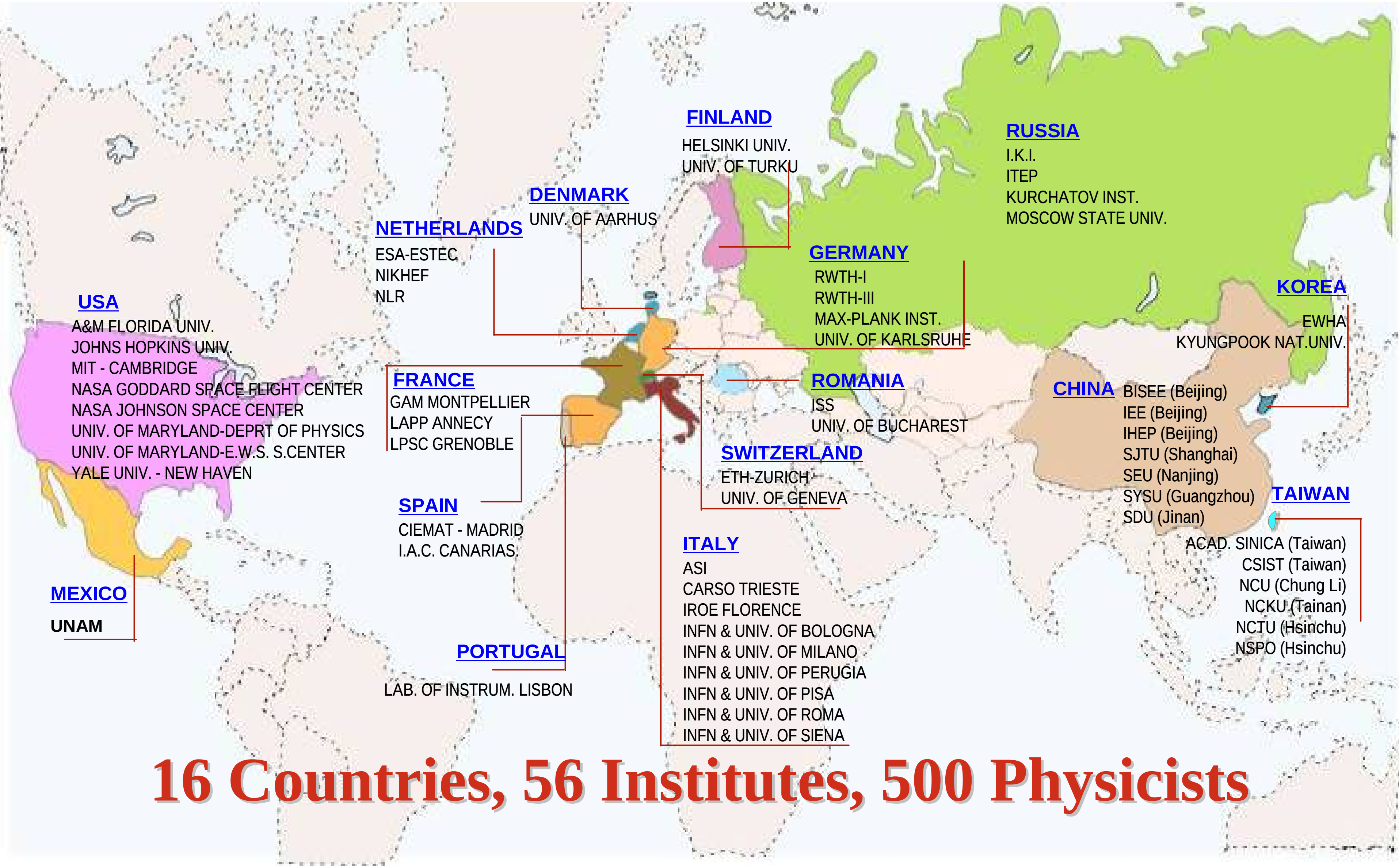
1- Neutral component:

Nobel Prizes,
(1) Pulsar,
(2) Microwave,
(3) Binary Pulsars,
(4) Solar neutrino
X Ray sources

2- Charged component: He, Be, C, Fe

AMS will be the 1st experiment to accurately measure the charged cosmic rays outside the magnetosphere.

International Commitments to AMS



USA

A&M FLORIDA UNIV.
JOHNS HOPKINS UNIV.
MIT - CAMBRIDGE
NASA GODDARD SPACE FLIGHT CENTER
NASA JOHNSON SPACE CENTER
UNIV. OF MARYLAND-DEPRT OF PHYSICS
UNIV. OF MARYLAND-E.W.S. S.CENTER
YALE UNIV. - NEW HAVEN

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UNAM

NETHERLANDS

ESA-ESTEC
NIKHEF
NLR

DENMARK

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GAM MONTPELLIER
LAPP ANNECY
LPSC GRENOBLE

SPAIN

CIEMAT - MADRID
I.A.C. CANARIAS.

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LAB. OF INSTRUM. LISBON

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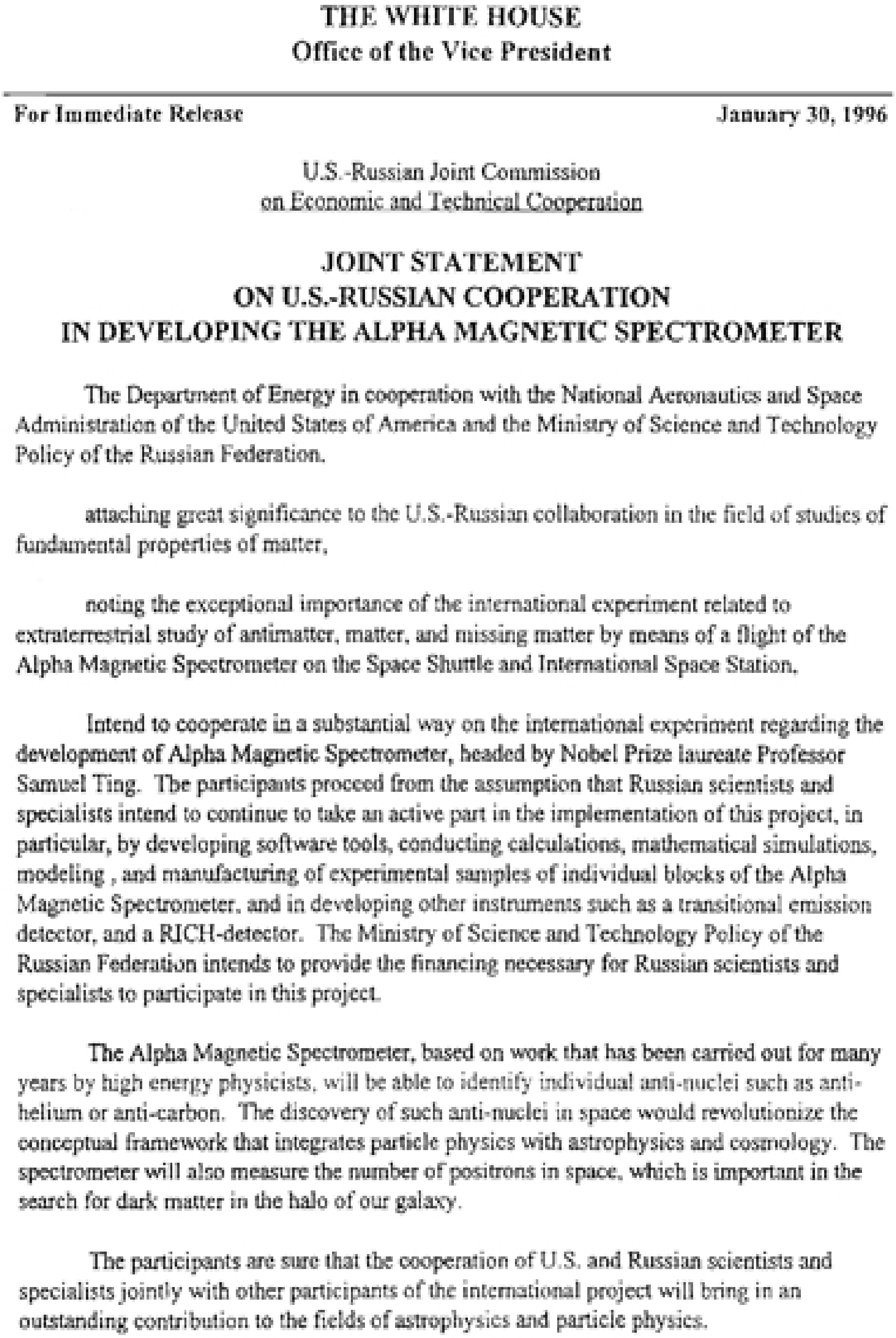
SYSU (Guangzhou)
SDU (Jinan)

TAIWAN

ACAD. SINICA (Taiwan)
CSIST (Taiwan)
NCU (Chung Li)
NCKU (Tainan)
NCTU (Hsinchu)
NSPO (Hsinchu)

16 Countries, 56 Institutes, 500 Physicists



THE WHITE HOUSE
Office of the Vice President

For Immediate Release **January 30, 1996**

U.S.-Russian Joint Commission
on Economic and Technical Cooperation

JOINT STATEMENT ON U.S.-RUSSIAN COOPERATION IN DEVELOPING THE ALPHA MAGNETIC SPECTROMETER

The Department of Energy in cooperation with the National Aeronautics and Space Administration of the United States of America and the Ministry of Science and Technology Policy of the Russian Federation.

attaching great significance to the U.S.-Russian collaboration in the field of studies of fundamental properties of matter,

noting the exceptional importance of the international experiment related to extraterrestrial study of antimatter, matter, and missing matter by means of a flight of the Alpha Magnetic Spectrometer on the Space Shuttle and International Space Station.

Intend to cooperate in a substantial way on the international experiment regarding the development of Alpha Magnetic Spectrometer, headed by Nobel Prize laureate Professor Samuel Ting. The participants proceed from the assumption that Russian scientists and specialists intend to continue to take an active part in the implementation of this project, in particular, by developing software tools, conducting calculations, mathematical simulations, modeling , and manufacturing of experimental samples of individual blocks of the Alpha Magnetic Spectrometer, and in developing other instruments such as a transitional emission detector, and a RICH-detector. The Ministry of Science and Technology Policy of the Russian Federation intends to provide the financing necessary for Russian scientists and specialists to participate in this project.

The Alpha Magnetic Spectrometer, based on work that has been carried out for many years by high energy physicists, will be able to identify individual anti-nuclei such as anti-helium or anti-carbon. The discovery of such anti-nuclei in space would revolutionize the conceptual framework that integrates particle physics with astrophysics and cosmology. The spectrometer will also measure the number of positrons in space, which is important in the search for dark matter in the halo of our galaxy.

The participants are sure that the cooperation of U.S. and Russian scientists and specialists jointly with other participants of the international project will bring in an outstanding contribution to the fields of astrophysics and particle physics.

AMS项目参加单位及人员

东南大学: 顾冠群 李 奇 宋爱国 冯纯伯 李建清 孟 桥 孙忠良
龚 俭 王 茜 卢荣军 刘新宁 邹采荣 黄洪斌 吴 桦 方仕雄
罗军舟 黄庆安 程 光 帅立国 等

上海交大: 谢绳武 叶庆好 丁文江 汪荣顺 程浩忠 刘 桦 庞乾骏
王如竹 姜建国 石剑虹 顾安忠 徐 烈 林万来 金之俭 敬忠良
崔容强 胡国新 林文胜 杜朝辉 黄林鹏 张 荻 乔卫新 等

中山大学: 许宁生 何振辉 郭开华 余世杰 倪江群 吕树申 李廷勋
姜孝华 祁新梅 黄以华 张 东 刘守圭 郑寿森 岳 薇 许功铎
等

山东大学: 程 林 过增元 栾 涛 王立秋 李 康 张树生 张洪才
杜文静 辛公明 郑继周 王世峰 宋继伟 刘 文 赵忠超 云和明
曲 燕 陈 岩 曹洪振 张玉相 等

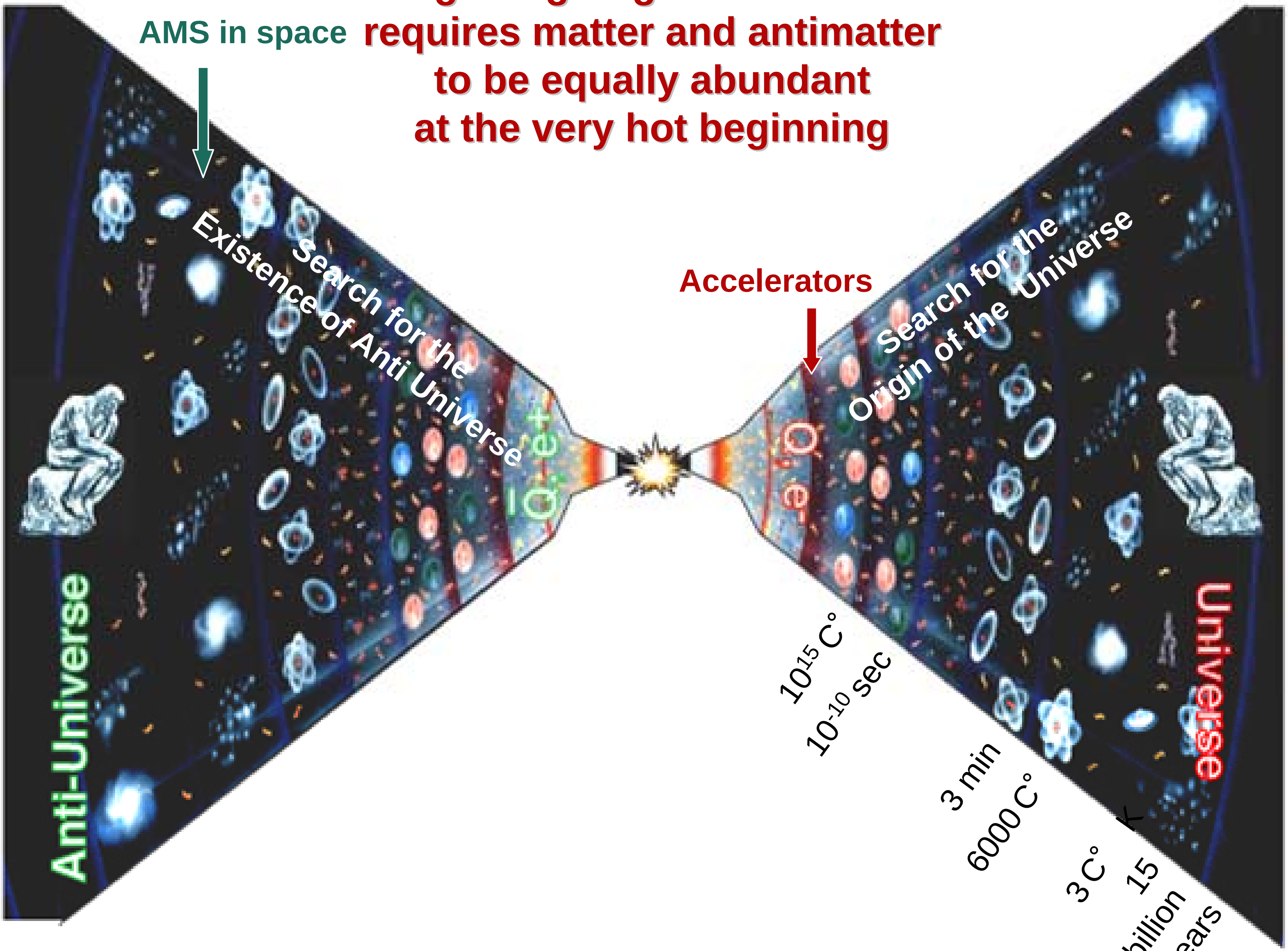
高能所，电工所: 陈和生 庄红林 吕雨生 杨长根 陈 刚 孔 力
余运佳 王秋良 于妙根 等

航天部一院、五院: 王 毅 李昌懋 彭小波 唐军刚 李 宁 殷立明
候增祺 向树红 张加迅 等

包头稀土研究所: 丁善宝 谢宏祖 郭炳麟 等

中科院空间中心: 张厚英 等

The Big Bang origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning



AMS in space

Accelerators

Search for the Existence of Anti Universe

Search for the Origin of the Universe

The Existence of Antimatter

Paul A.M. Dirac

Theory of electrons and positrons

Nobel Lecture, December 12, 1933

Relativity:

$$\frac{W^2}{c^2} - p_{r^2} - m^2 c^2 = 0$$

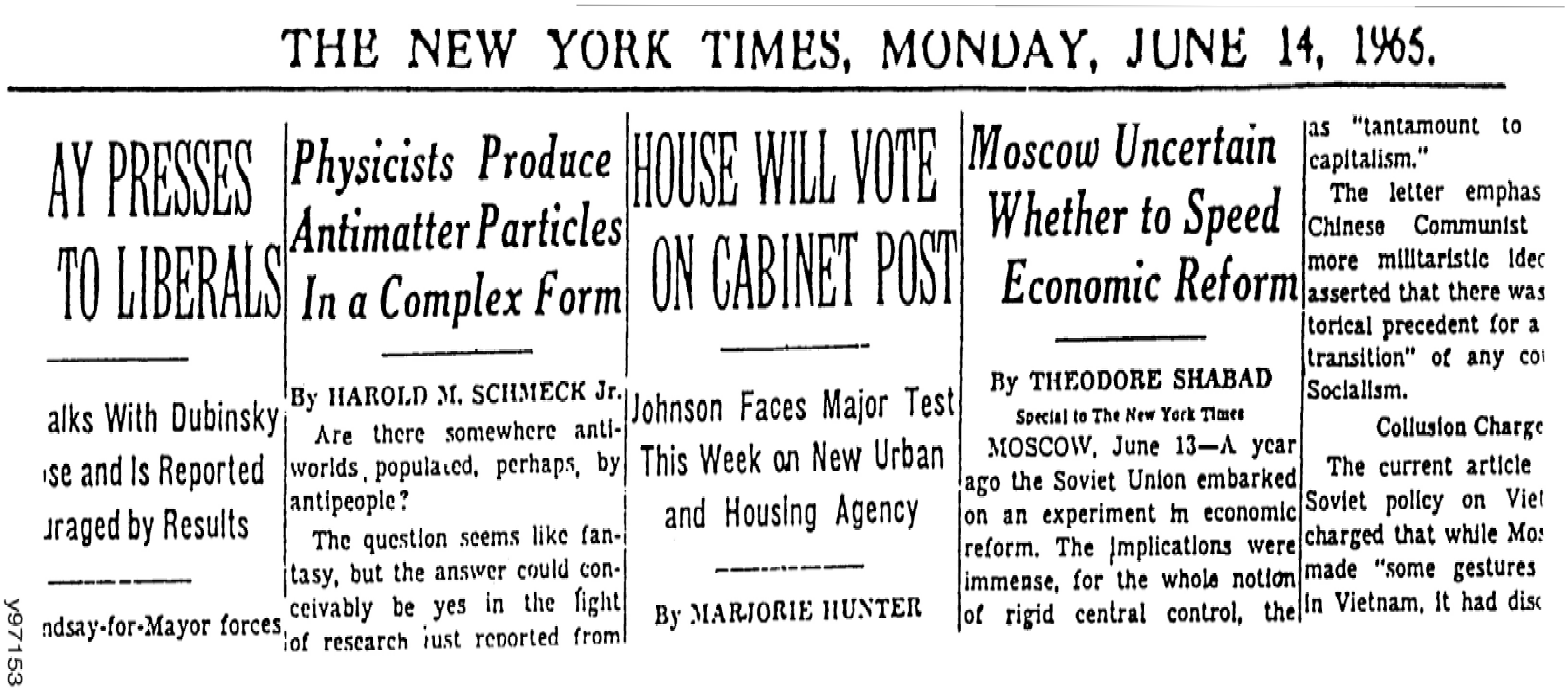
Quantum Theory:

$$\left[\frac{W^2}{c^2} - p_{r^2} - m^2 c^2 \right]\Psi = 0$$

$$m^2 = (m)(m) = (-m)(-m)$$

Dirac asked: What is (-m) → Theory of antimatter

The discovery of nuclear antimatter



THE NEW YORK TIMES, MONDAY, JUNE 14, 1965.

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alks With Dubinsky
ıse and Is Reported
ıraged by Results

ndsay-for-Mayor forces

Physicists Produce Antimatter Particles In a Complex Form

By HAROLD M. SCHMECK Jr.

Are there somewhere antiworlds, populated, perhaps, by antipeople?

The question seems like fantasy, but the answer could conceivably be yes in the light of research just reported from

HOUSE WILL VOTE ON CABINET POST

Johnson Faces Major Test This Week on New Urban and Housing Agency

By MARJORIE HUNTER

Moscow Uncertain Whether to Speed Economic Reform

By THEODORE SHABAD

Special to The New York Times

MOSCOW, June 13—A year ago the Soviet Union embarked on an experiment in economic reform. The implications were immense, for the whole notion of rigid central control, the

as "tantamount to capitalism."

The letter emphas
Chinese Communist
more militaristic idec
asserted that there was
torical precedent for a
transition" of any co
Socialism.

Collusion Charg

The current article
Soviet policy on Viet
charged that while Mos
made "some gestures
in Vietnam, it had disc

y97153

Matter

Deuteron = proton + neutron

Anti-Matter

anti-Deuteron = anti-proton + anti-neutron

《参考消息》1965年05月14日以“中国旅美科学家发现‘双逆料子’”为题，转载报道：

【本刊讯】蒋帮《中央日报》三月十三日报道：

据《纽约时报》本月三日载华盛顿美联社电，布罗克海温实验所主任荀海伯博士在国会原子能小组委员会作证时宣布，由哥伦比亚大学丁肇中博士与李得曼博士所主持之研究小组，应用该所设备之三千三百亿（原文如此，应为三百三十亿——本刊注）电子伏原子冲击器已产生“重氢核之双逆粒子”，此项双逆粒子约在一百万“逆正子”中始得寻获一个，为高能物理学首次发现。

按:丁氏现年二十八岁，现与科学家李政道、吴健雄共执教于哥伦比亚大学物理系，父为名数学及力学教授丁观海氏。

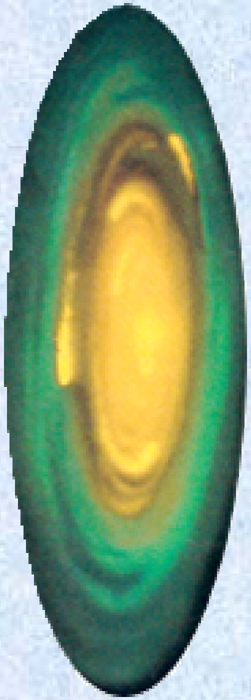
Particles	Anti-particles
e^- *(electron)*	*(positron)* e^+
P^+ *(proton)*	*(anti proton)* P^-
π^-	π^+
K^-	K^+
D^+	D^-

Question

Universe

He

C



Anti universe ?

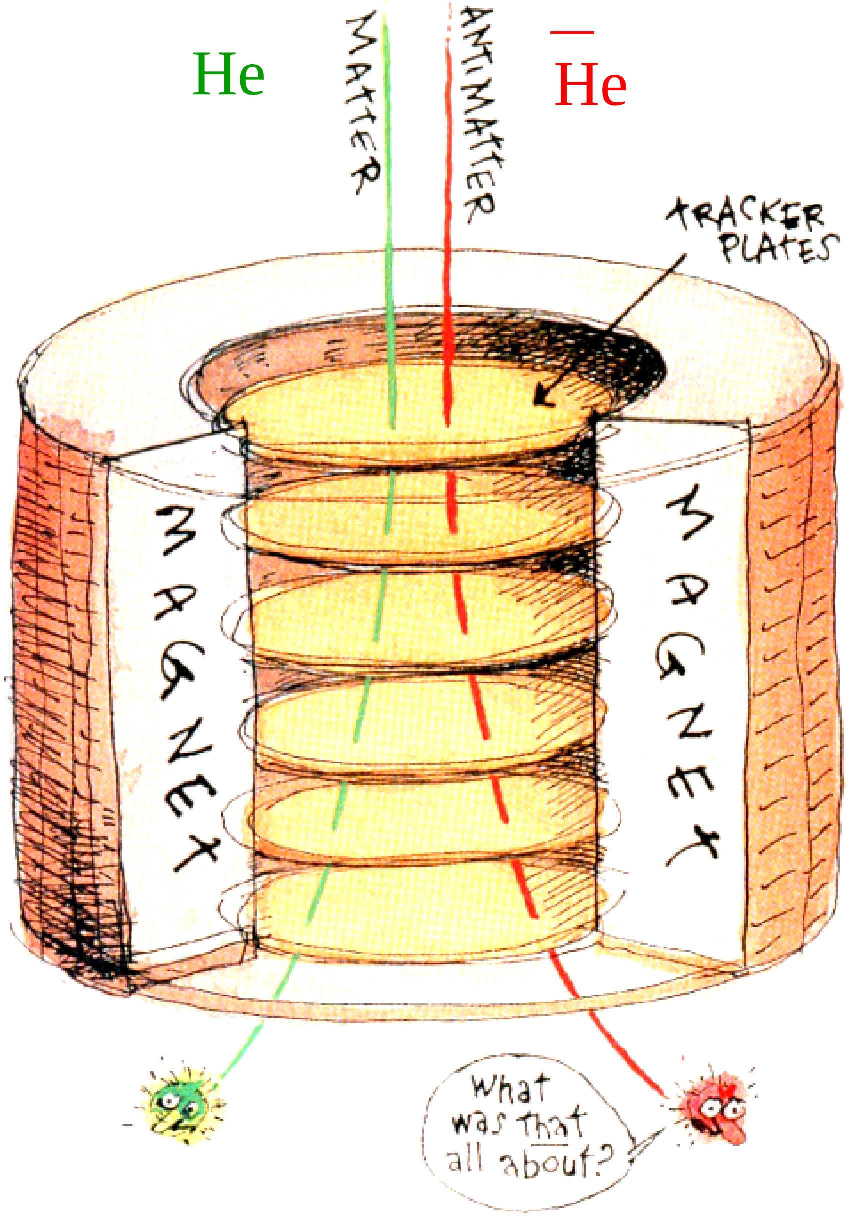
$\overline{\text{He}}$

$\overline{\text{C}}$

Cosmic antimatter cannot be detected on earth because matter and antimatter will annihilate each other in the atmosphere

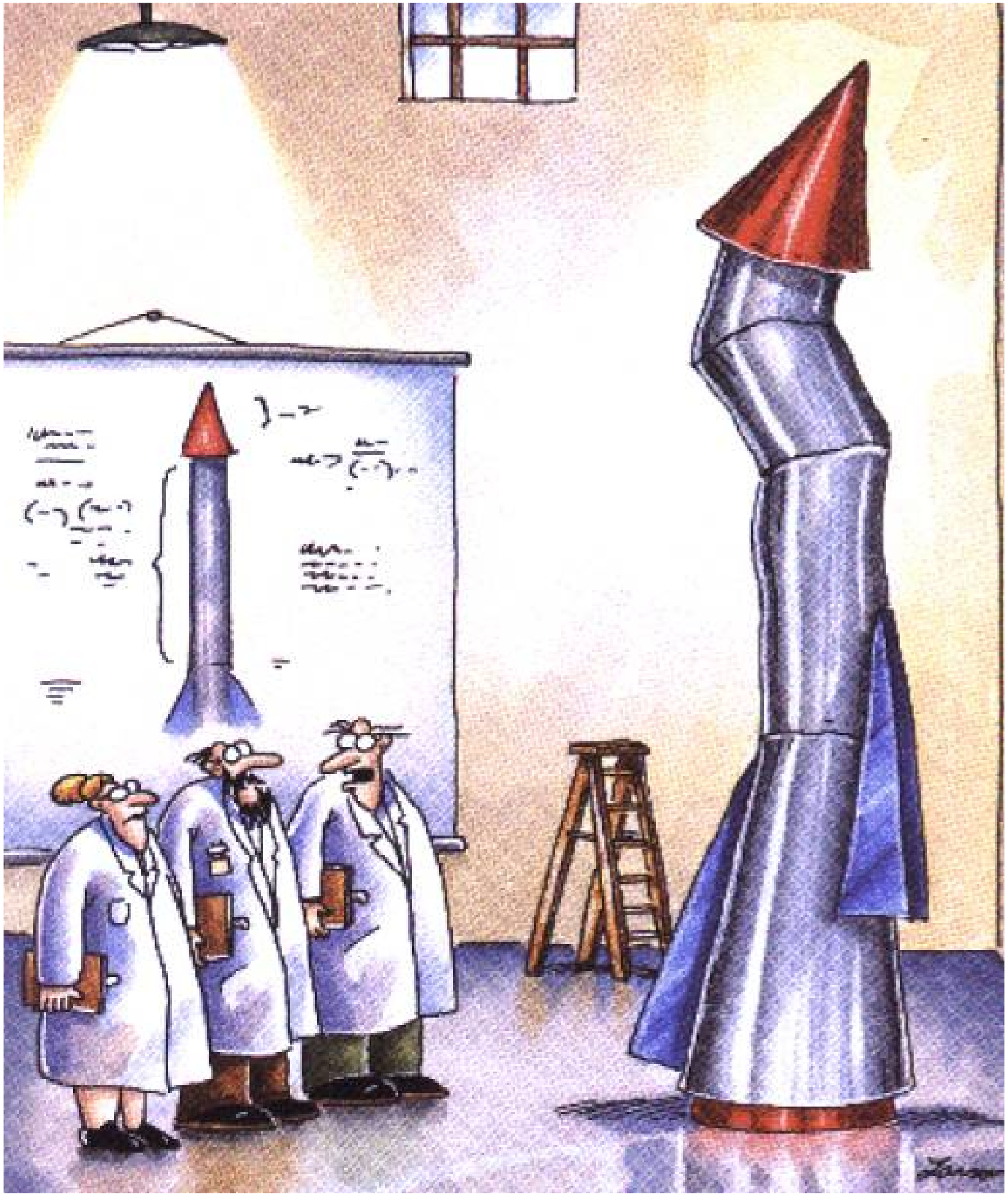
Matter and antimatter have opposite electric charges;

we need a magnetic detector to measure the charge of antimatter.



Air and Space
Smithsonian Institution, May 2001

y02K042b



"Its time we face reality,

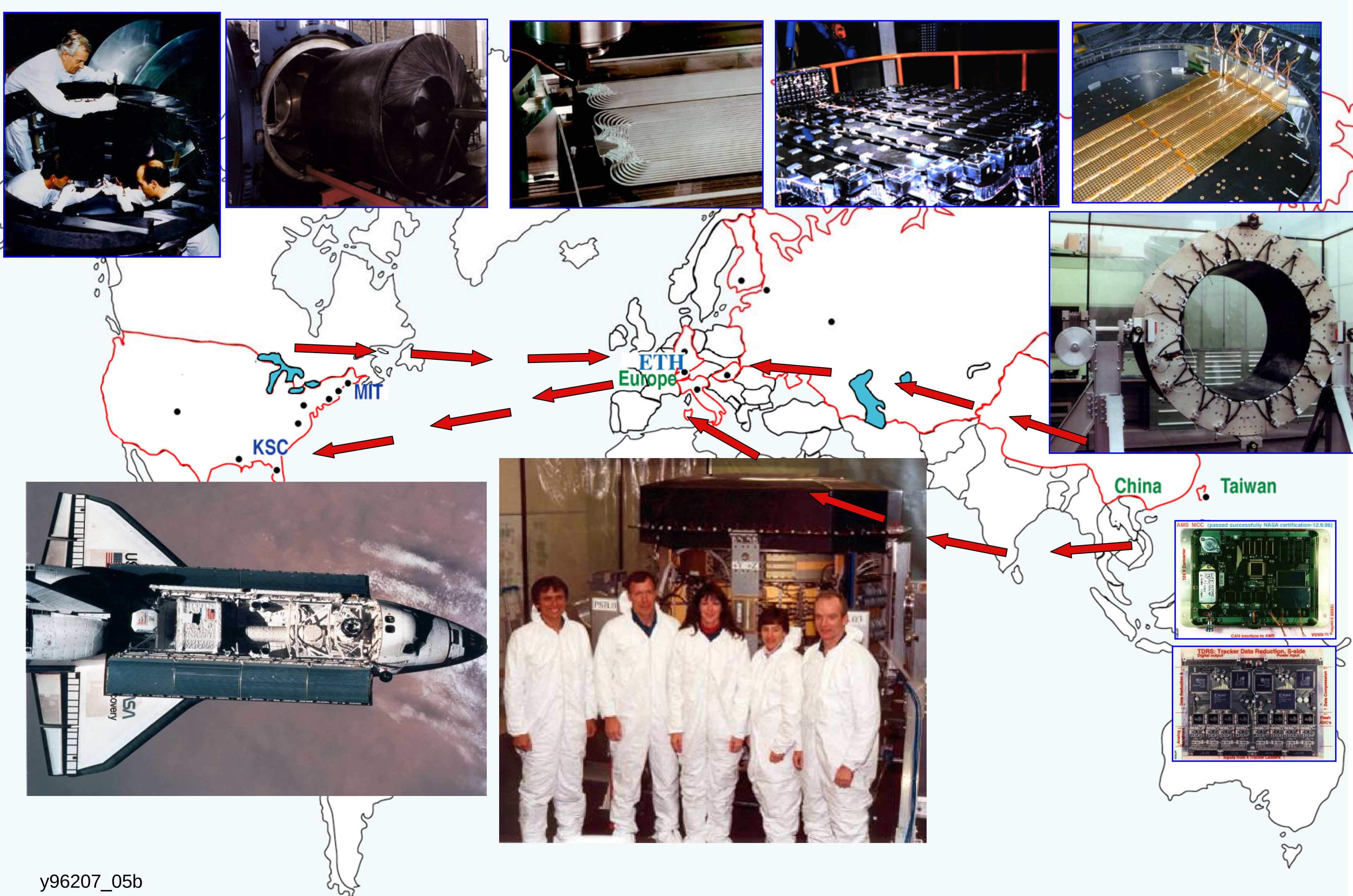
my friends….

We're not exactly

rocket scientists."

First flight AMS-01

Approval: April 1995, Assembly: December 1997, Flight: June 1998



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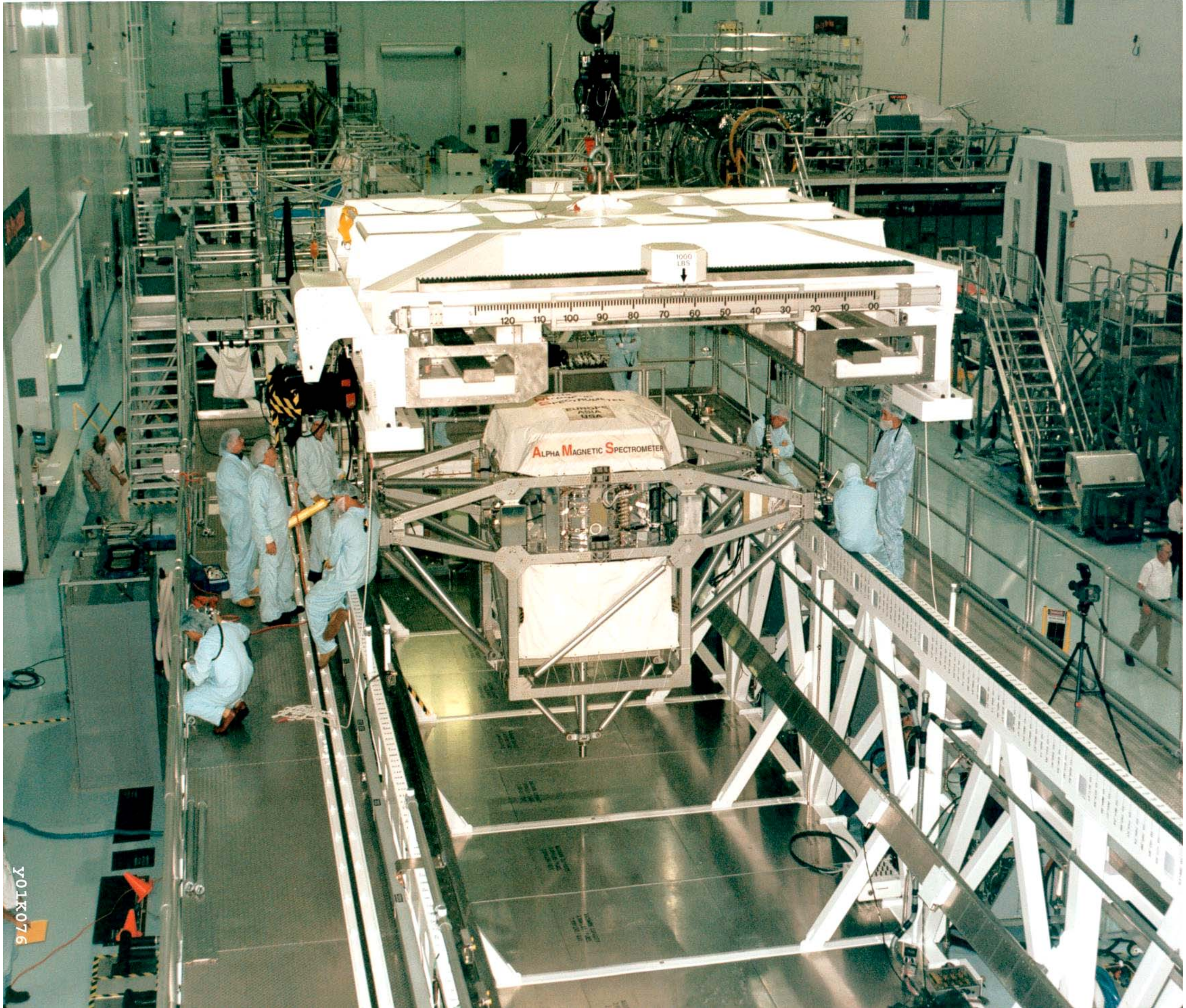
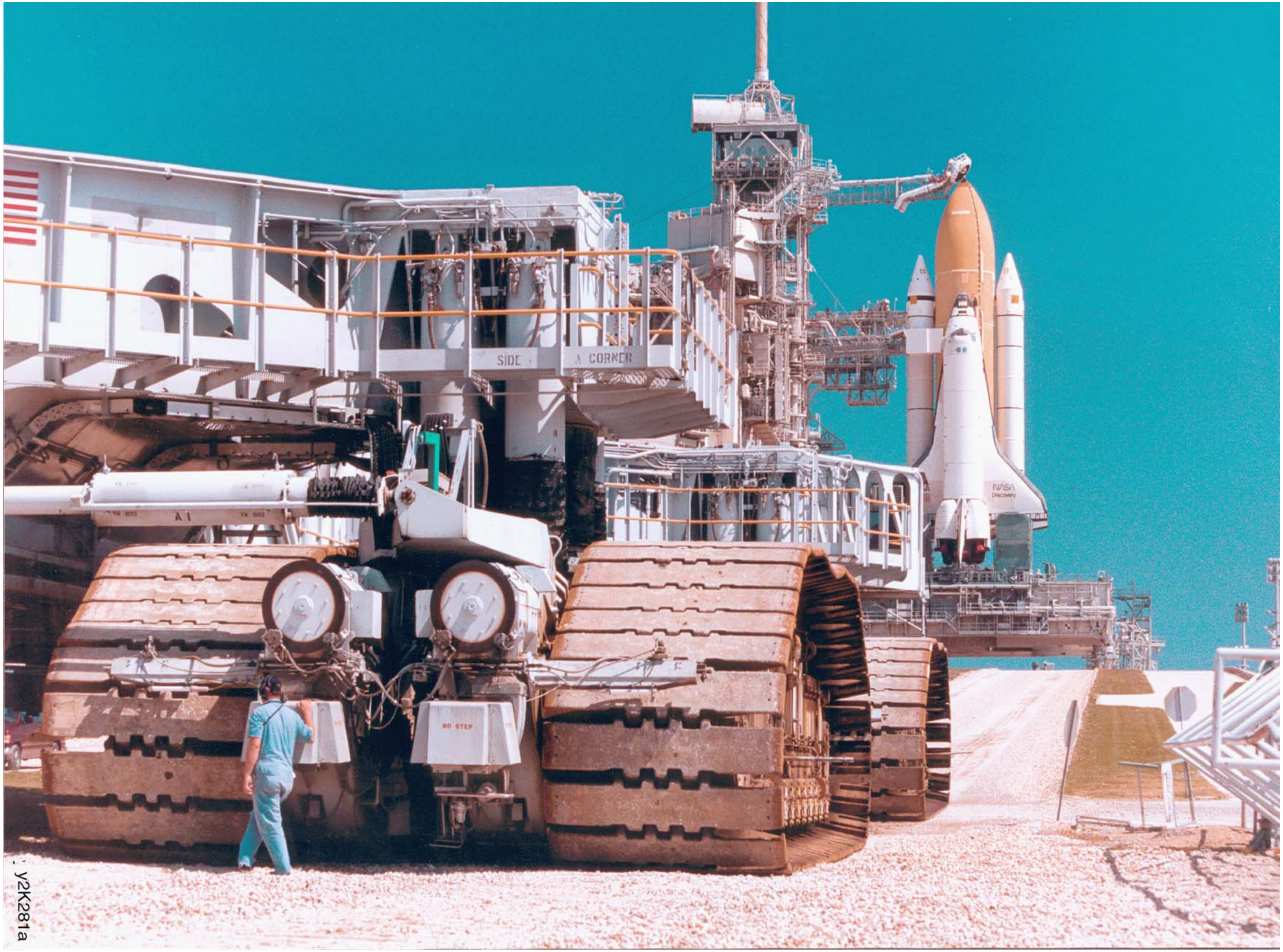


1000 LBS
120 110 100 90 80 70 60 50 40 30 20 10 00
ALPHA MAGNETIC SPECTROMETER
EUROPE ASIA USA
Y01K076


SIDE
A CORNER
A1
NO STEP
NASA
Discovery
y2K281a


USA
NASA
Atlantis

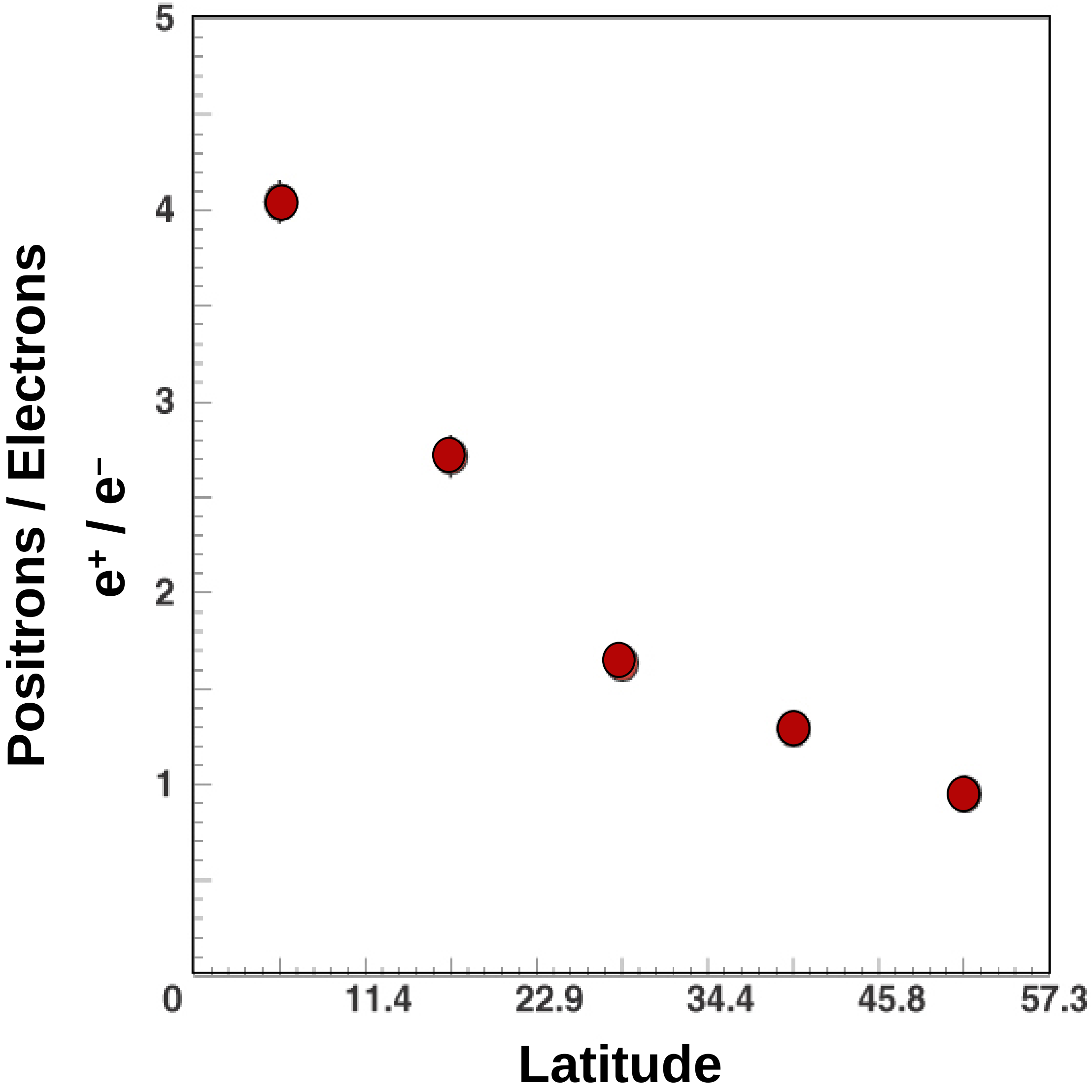
National Aeronautics and
Space Administration

NASA7-726-068

Lyndon B. Johnson Space Center
Houston, Texas 77058

AMS paper: “Leptons in Near Earth Orbit”

Physics Letters B 484 (2000) p. 10-22



1998年世界十大科技新闻

一、“月球勘察者”号发现月球上有冰态水

二、各国着手解决计算机2000年问题

三、天文学家认为宇宙的膨胀正在加速

四、科学家确认中微子有静止质量

五、阿尔法磁谱仪首次升空运行正常：6月2日，装有中国制造的巨大永磁体的阿尔法磁谱仪首次搭乘美国发现号航天飞机升空。此磁谱仪将安装于未来的国际空间站，用以探测宇宙中的反物质粒子。在此次实验中阿尔法磁谱仪运行正常。

六、地面数字电视节目开始播放

七、“铱”星全球电话系统开通

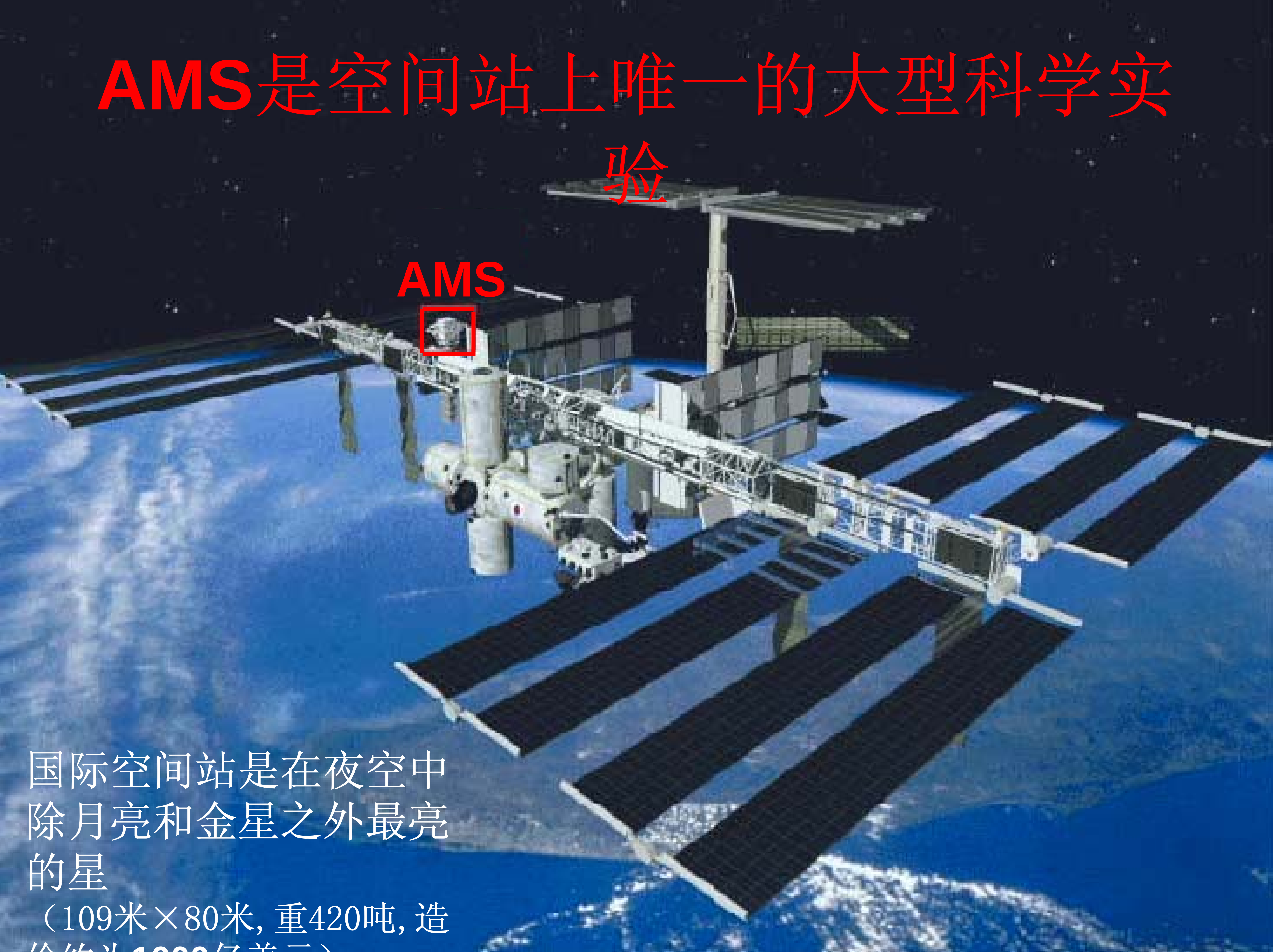
八、DNA测序技术有新进展

九、国际空间站开始组建

十、物理学家发现首例违背时间对称性现象

（摘自1998年12月29日《科技日报》）

AMS是空间站上唯一的大型科学实验



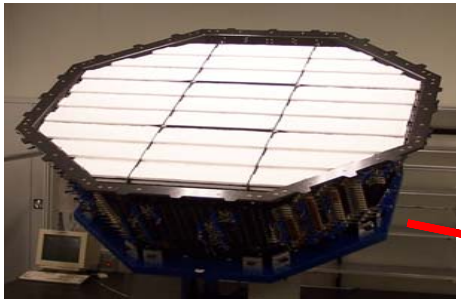
国际空间站是在夜空中除月亮和金星之外最亮的星

（109米×80米，重420吨，造价约为1000亿美元）

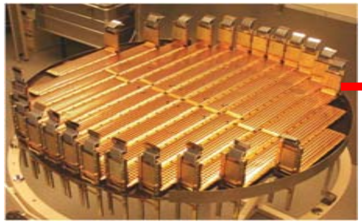
AMS: A Magnetic Spectrometer on ISS to study high energy TeV (10^{12} eV) Cosmic Rays

Construction of the detectors is complete.

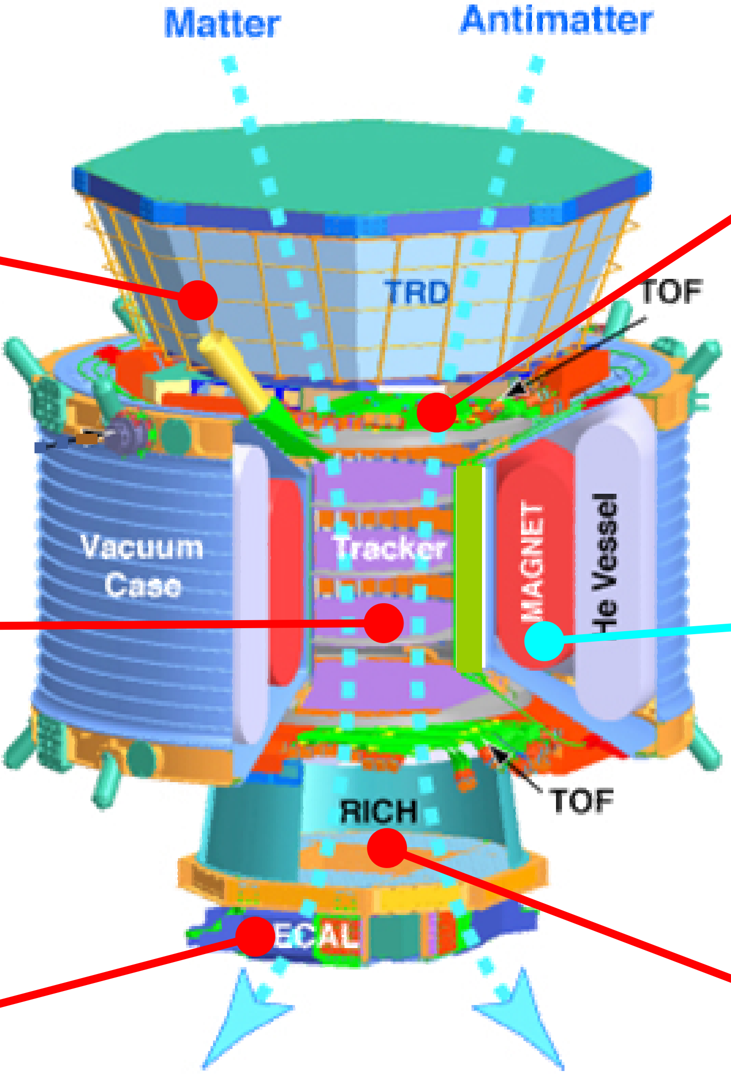
TRD
measures electrons



Silicon Tracker
measures nuclei
& their momentum



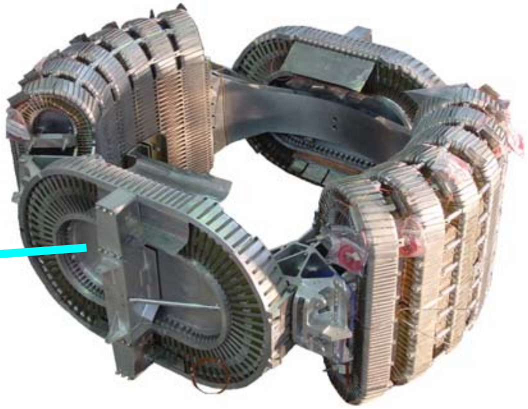
Calorimeter
Measures light rays
& electrons



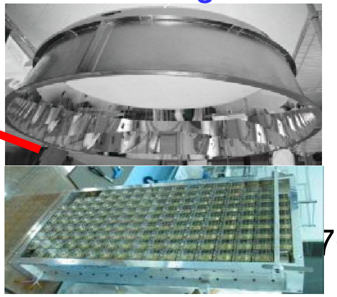
Size: 3m x 3m x3m
Weight: 7 tons

Time of Flight
measures velocity

Magnet
measures momentum



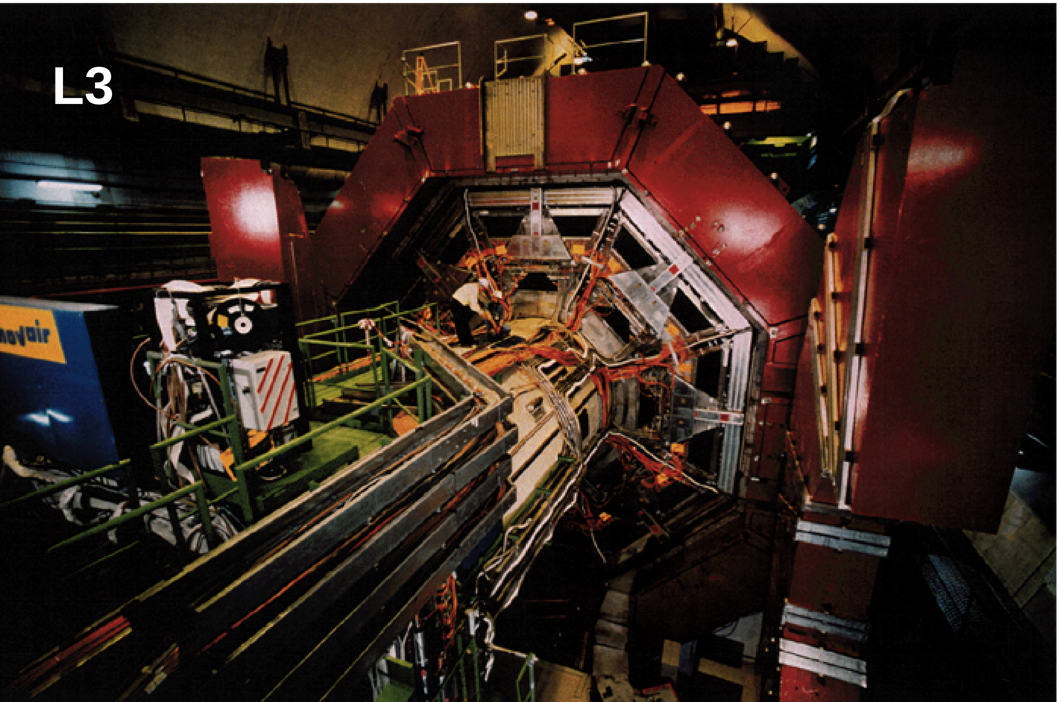
RICH
measures velocity
& charge

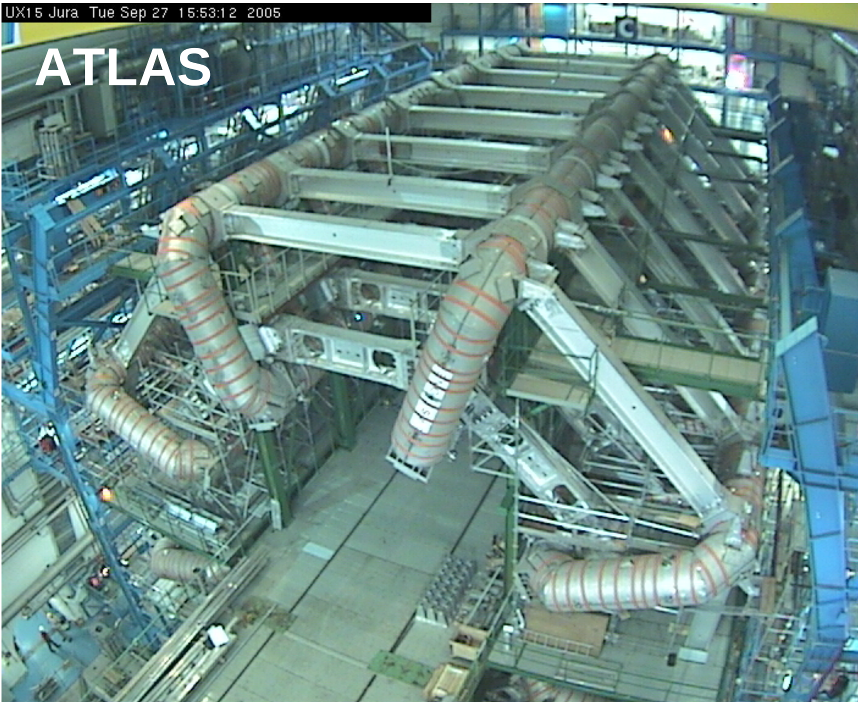


New Technology: Superconducting Magnet in Space

There has never been a superconducting magnet in space for long duration, due to the extremely difficult technical challenges

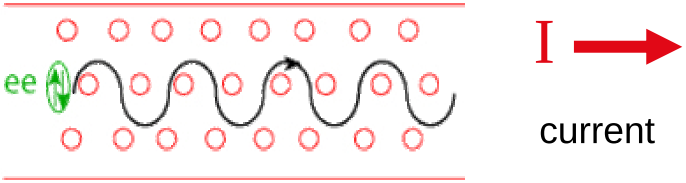
	Magnet on the Ground:	Magnet in Space:
Weight:	100 – 10,000 tons	1 ton
Volume:	As large as a 6-story building	Must fit in Shuttle
Power:	~ 10 Megawatts	0
Reliability:	~50 years experience	No experience





100 Years of Super Conductivity

Super-Conduction at -452° F



At this low temperature the atoms are at rest,
pairs of electrons move without friction
Allowing large currents with no losses

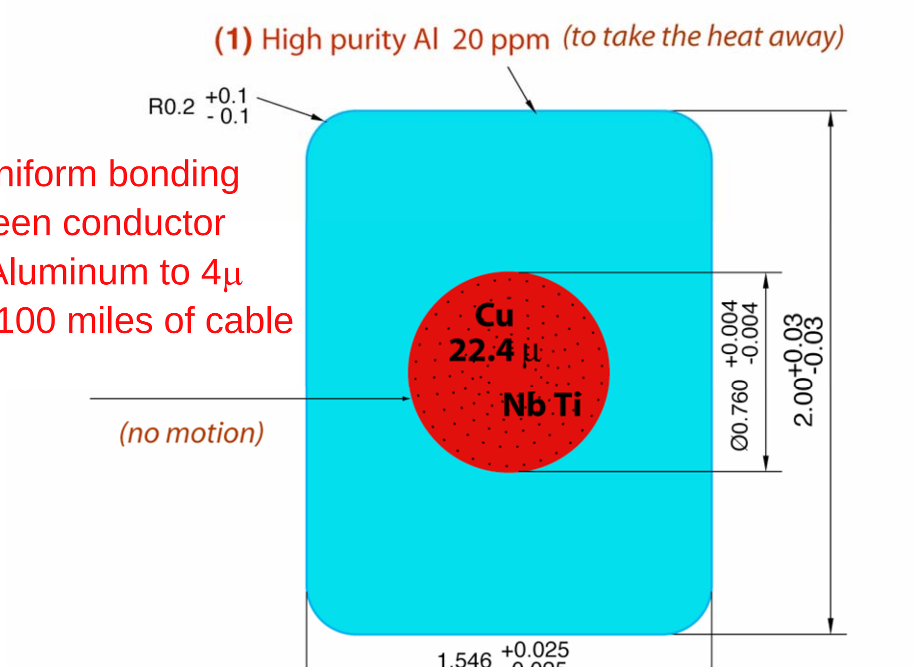
Quench: Loss of superconductivity
due to local micro-heating

SSC: started in 1983, cancelled in 1993
due to quench issues

New technology :

We developed a new type of superconducting cable which eliminated quench

(2) Uniform bonding between conductor and Aluminum to 4μ over 100 miles of cable



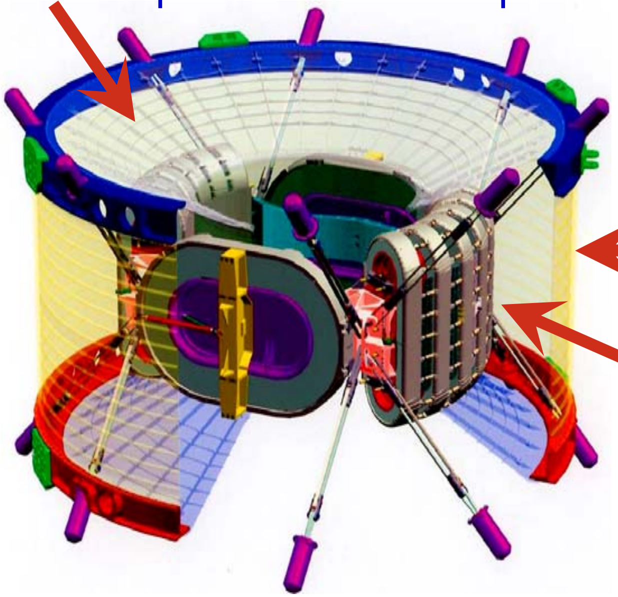
Technique now widely used in industry

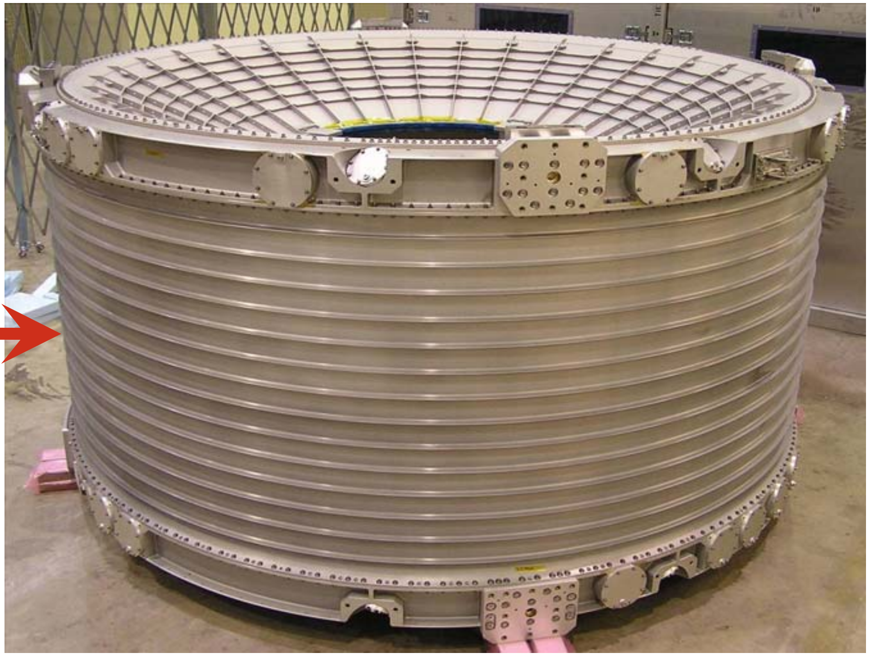
Tests at -456.43° F:
It is not possible to quench the coils except by outside heating

The AMS Superconducting magnet

2,500 liters of helium at -456.43° F

Becomes superfluid He^{II} with special properties



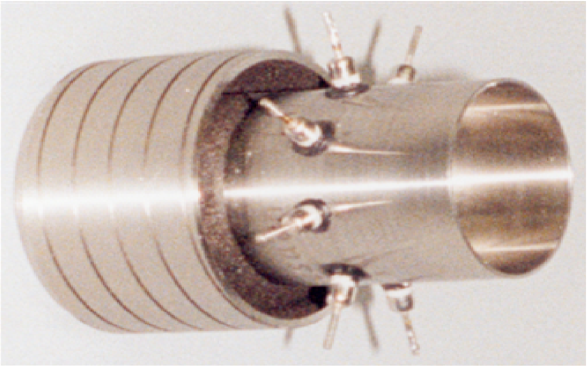


Vacuum Tank

Coils

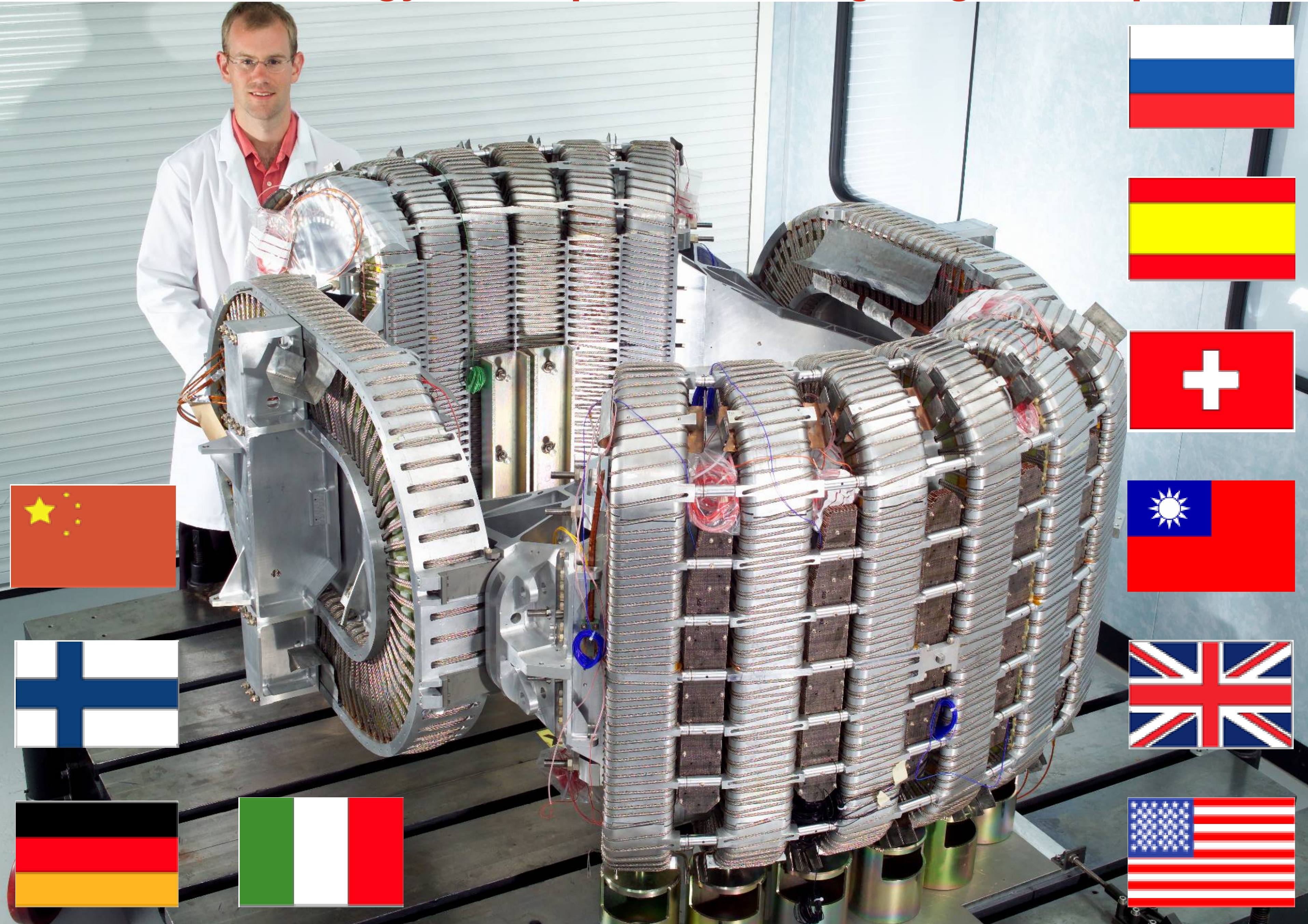
New Technologies at -456.43° F, under microgravity in strong magnetic field

1. ThermoMechanical Pump
Transfer superfluid He in space



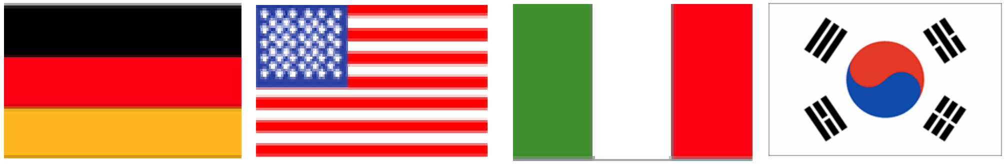
2. Phase separator
removes gas
from the He tank

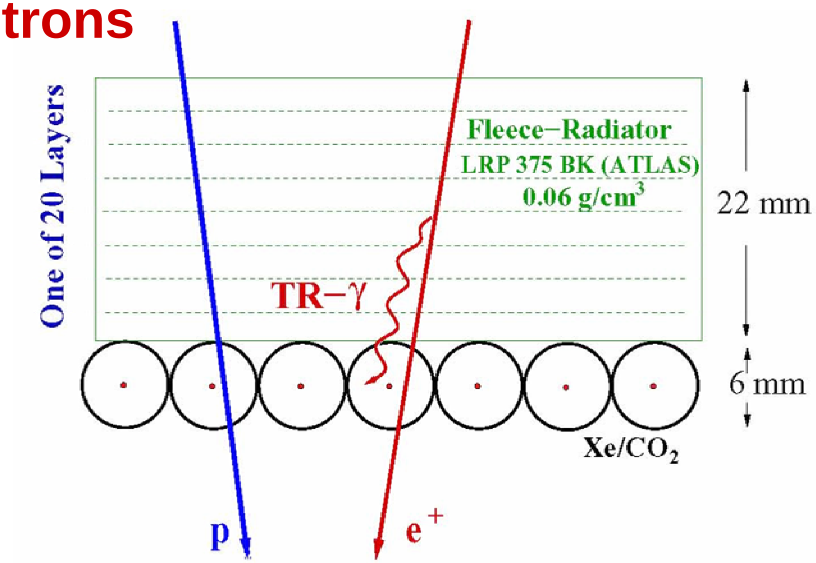
New Technology: 1st Superconducting Magnet in Space

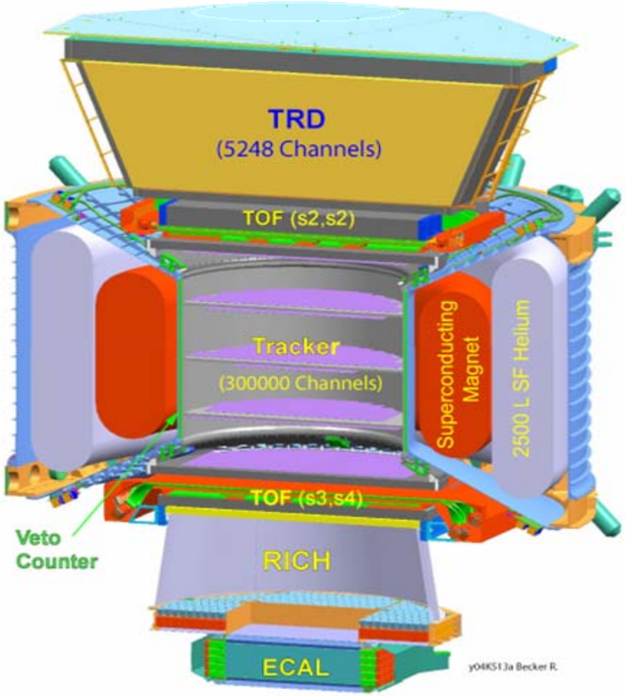


Transition Radiation Detector: TRD

Measures electrons





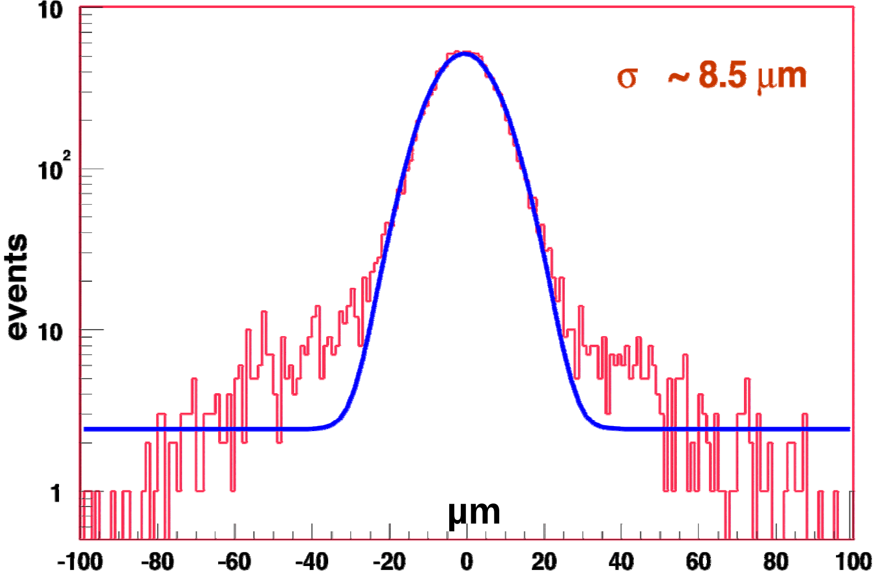


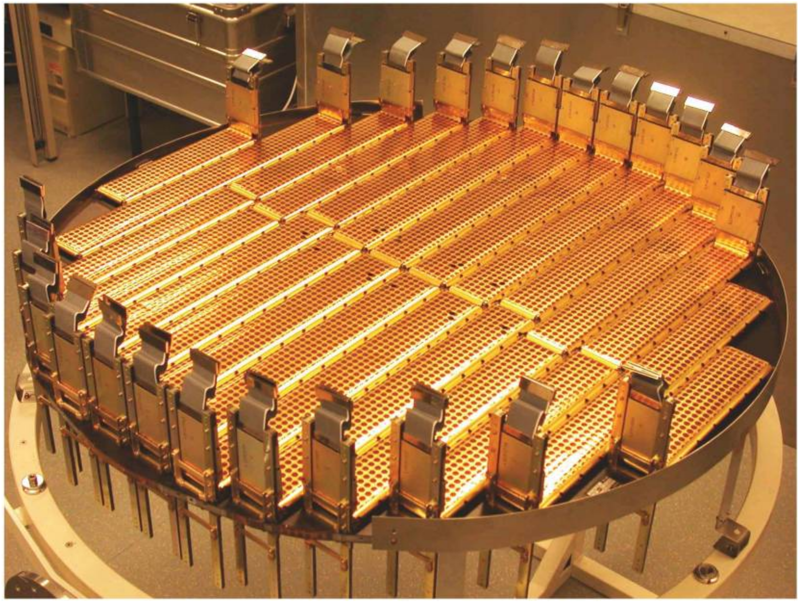
Coordinate resolution ~ 100 micron

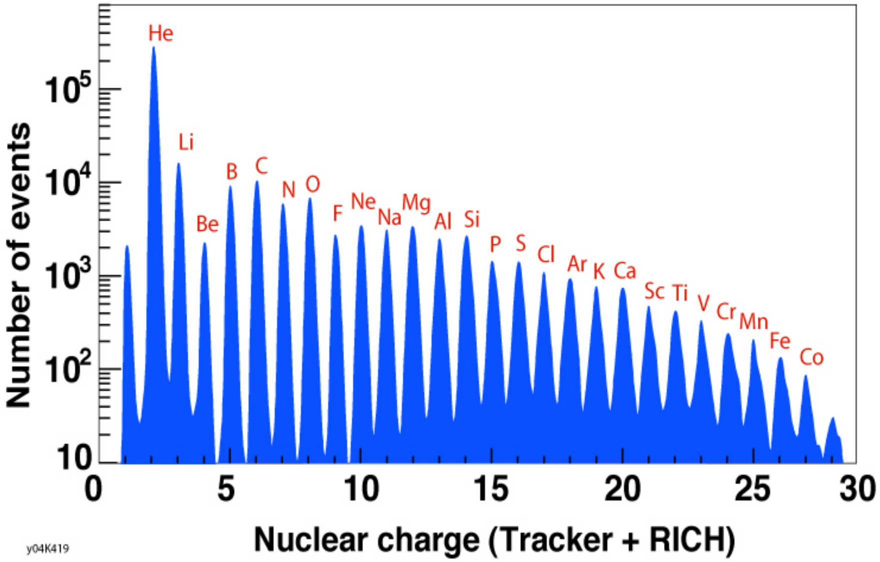
1 micron = 1 millionth of a yard

New technology in space: 6.6 m^2 of high precision Silicon Tracker

Production completed. Test results from accelerator:

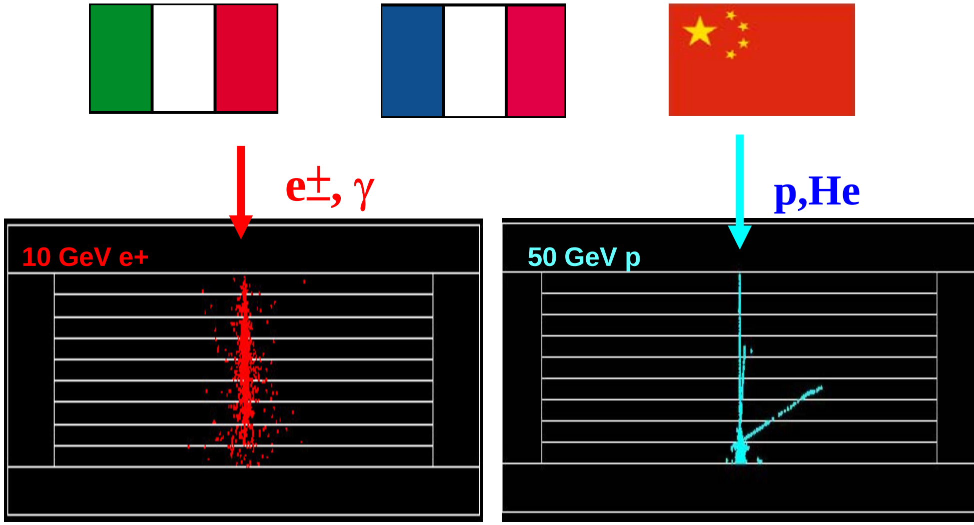


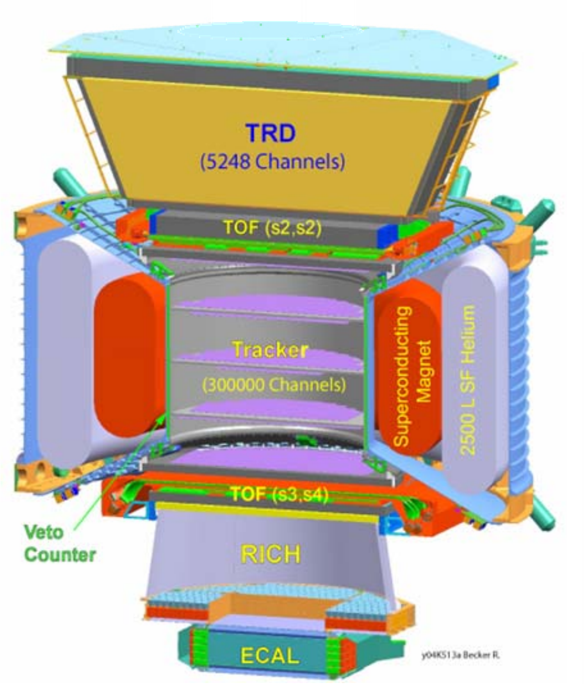




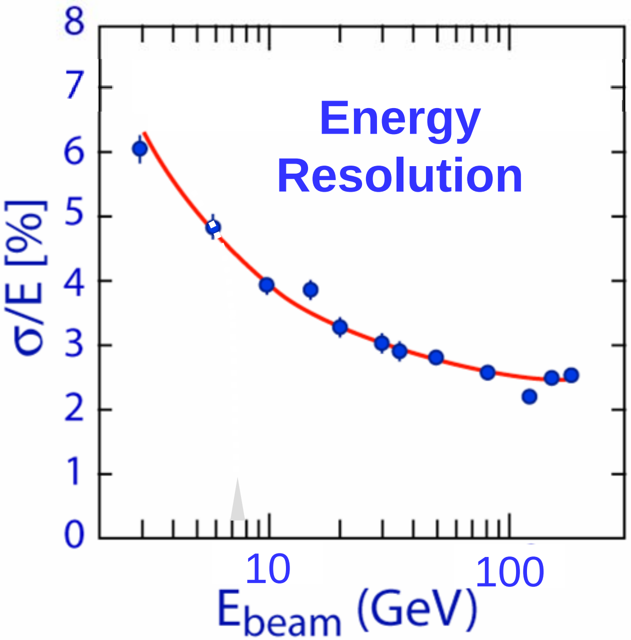
Finish the assembly by October 2004

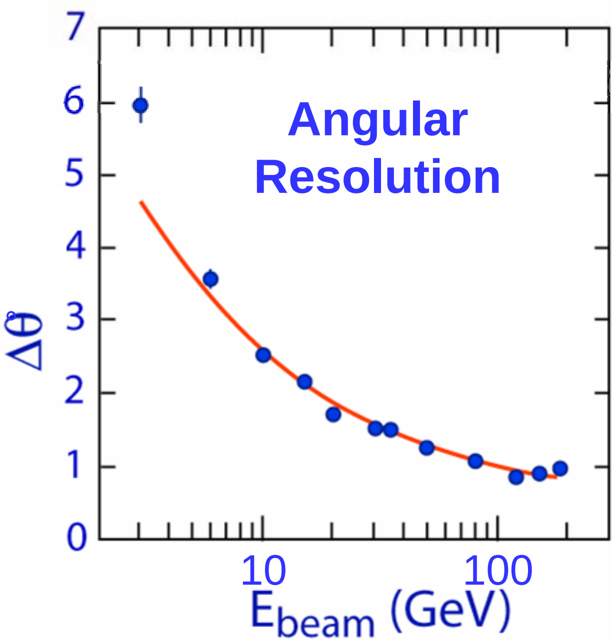
A 3 dimensional measurement of the direction and energy of light rays and electrons: ECAL





Verified by accelerator calibration



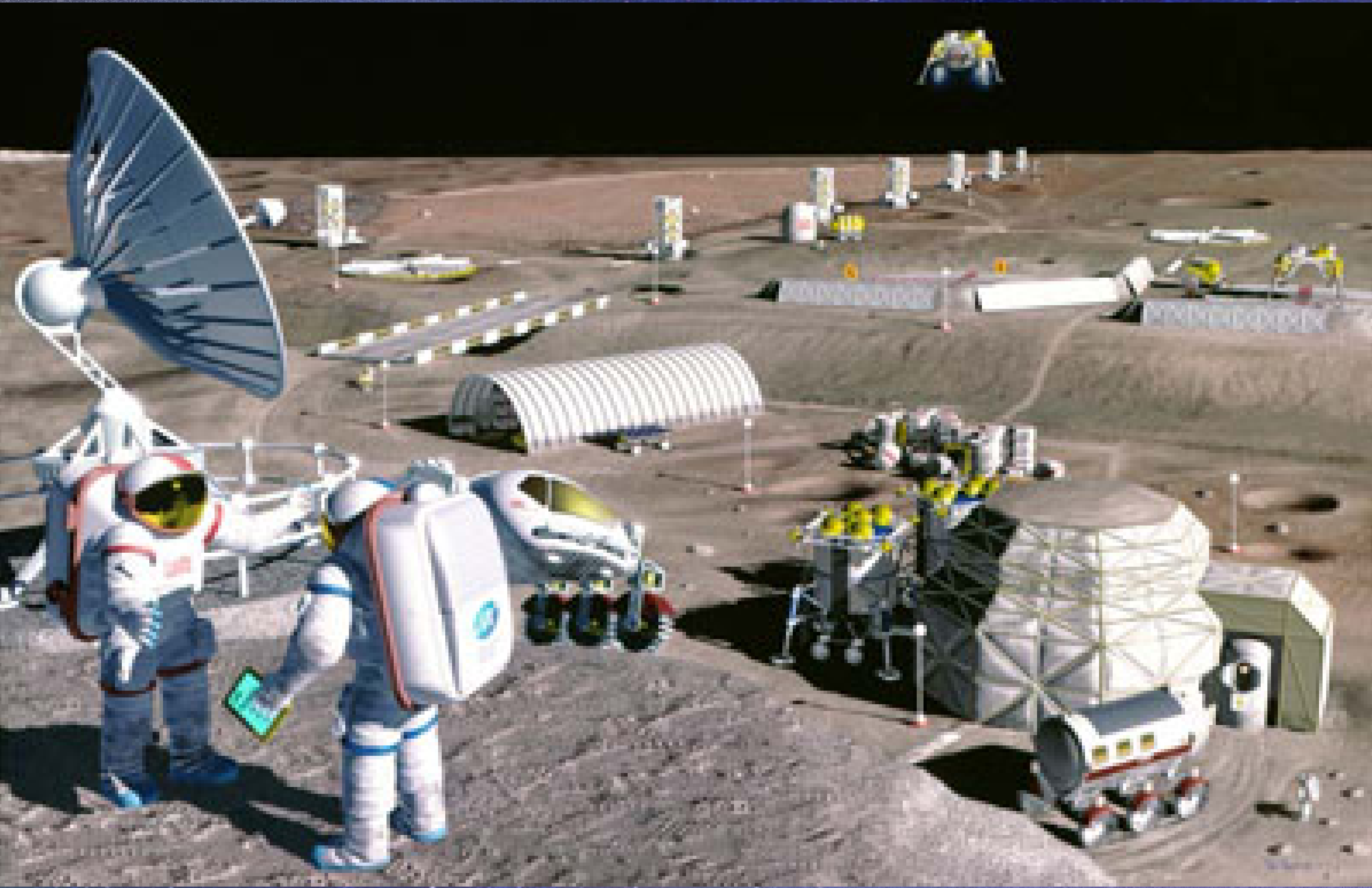


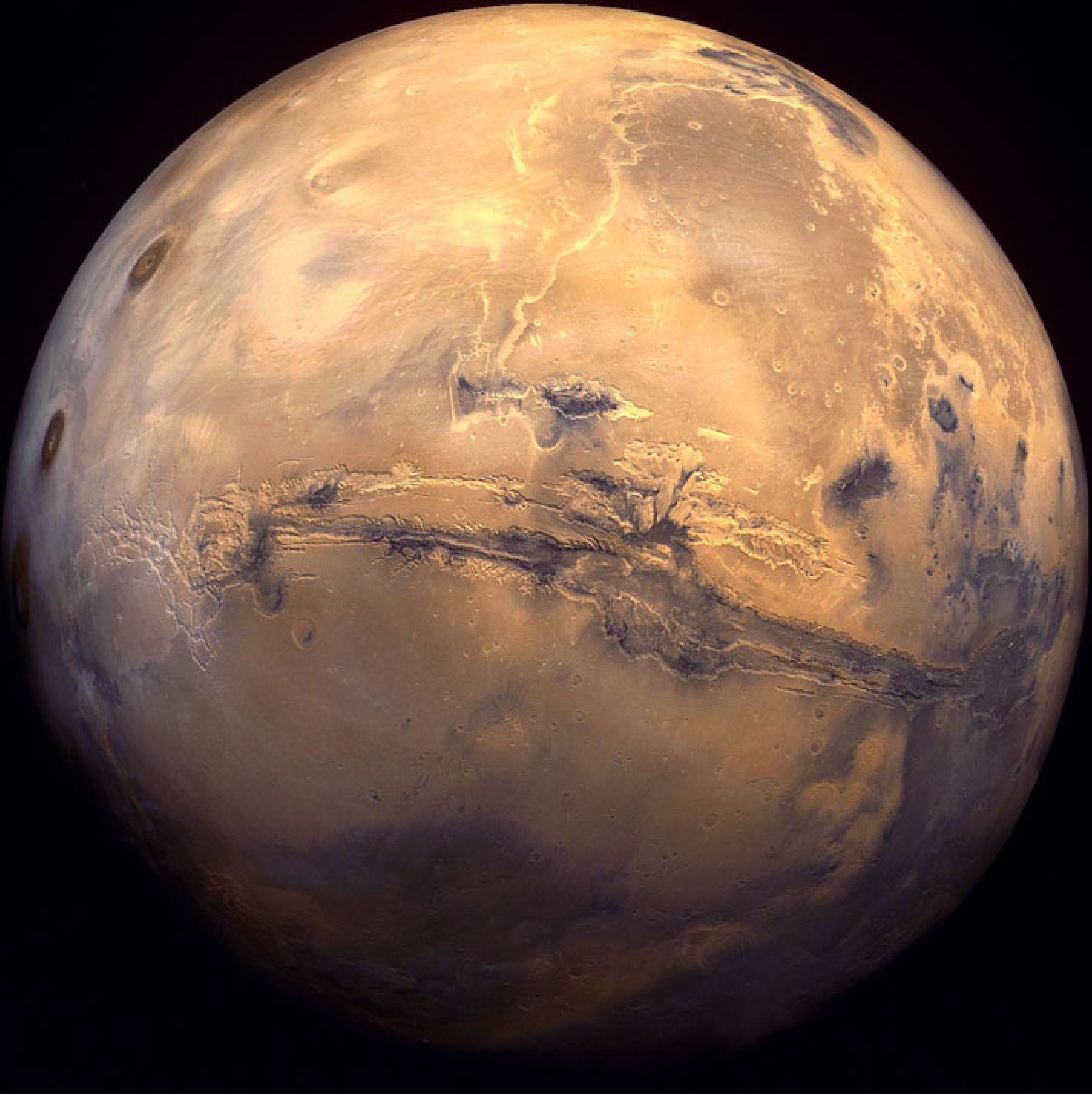
Office of Exploration Systems

Program Overview

March 2 - 3, 2004

Associate Administrator,
Office of Exploration Systems
Rear Admiral Craig E. Steidle (Ret.)

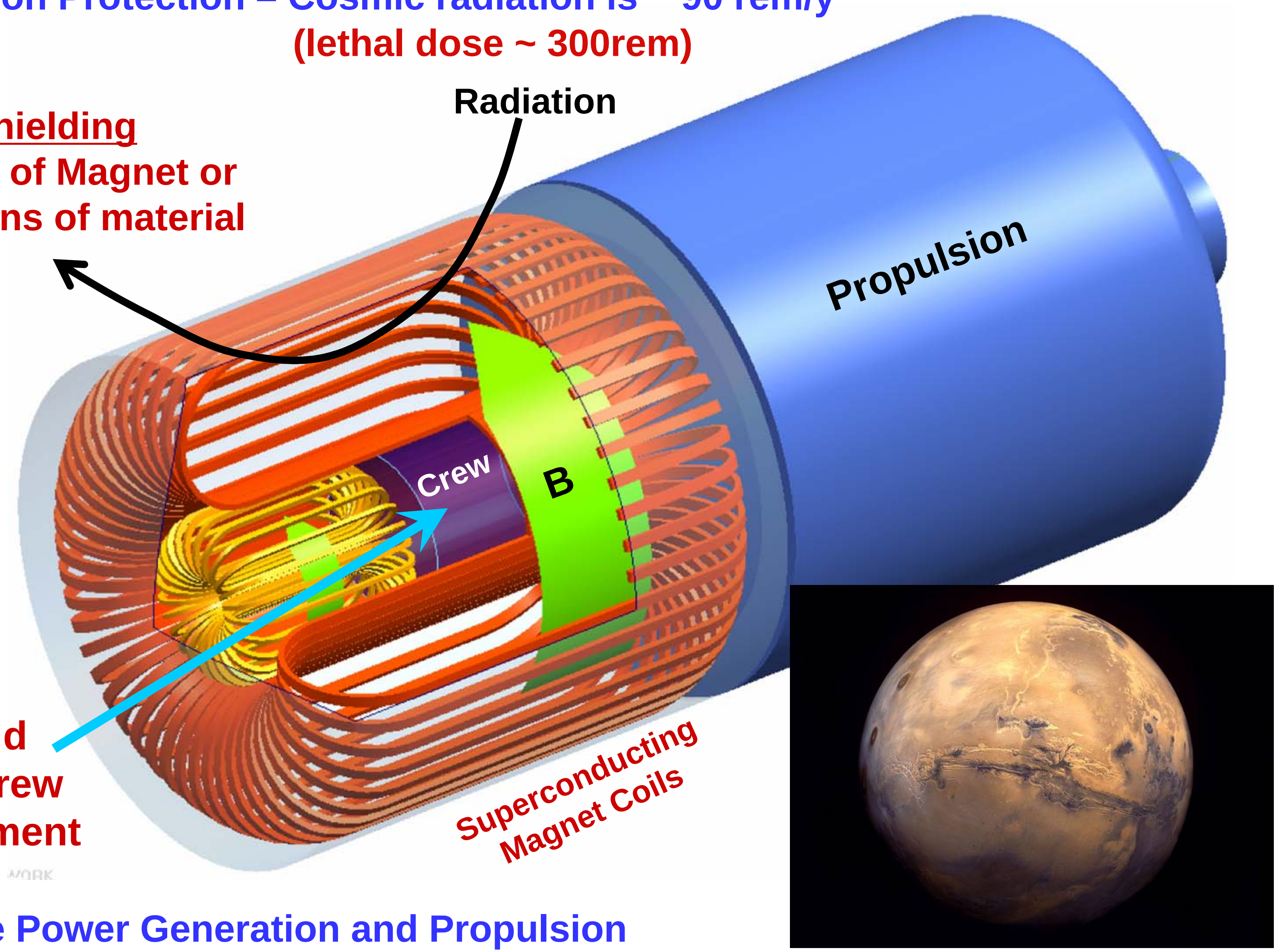





YANKEE GO HOME!
MARS FOR MARTIANS
SPIRIT

Applications of AMS Technology to Exploration:

1. Radiation Protection – Cosmic radiation is ~ 90 rem/y (lethal dose ~ 300rem)

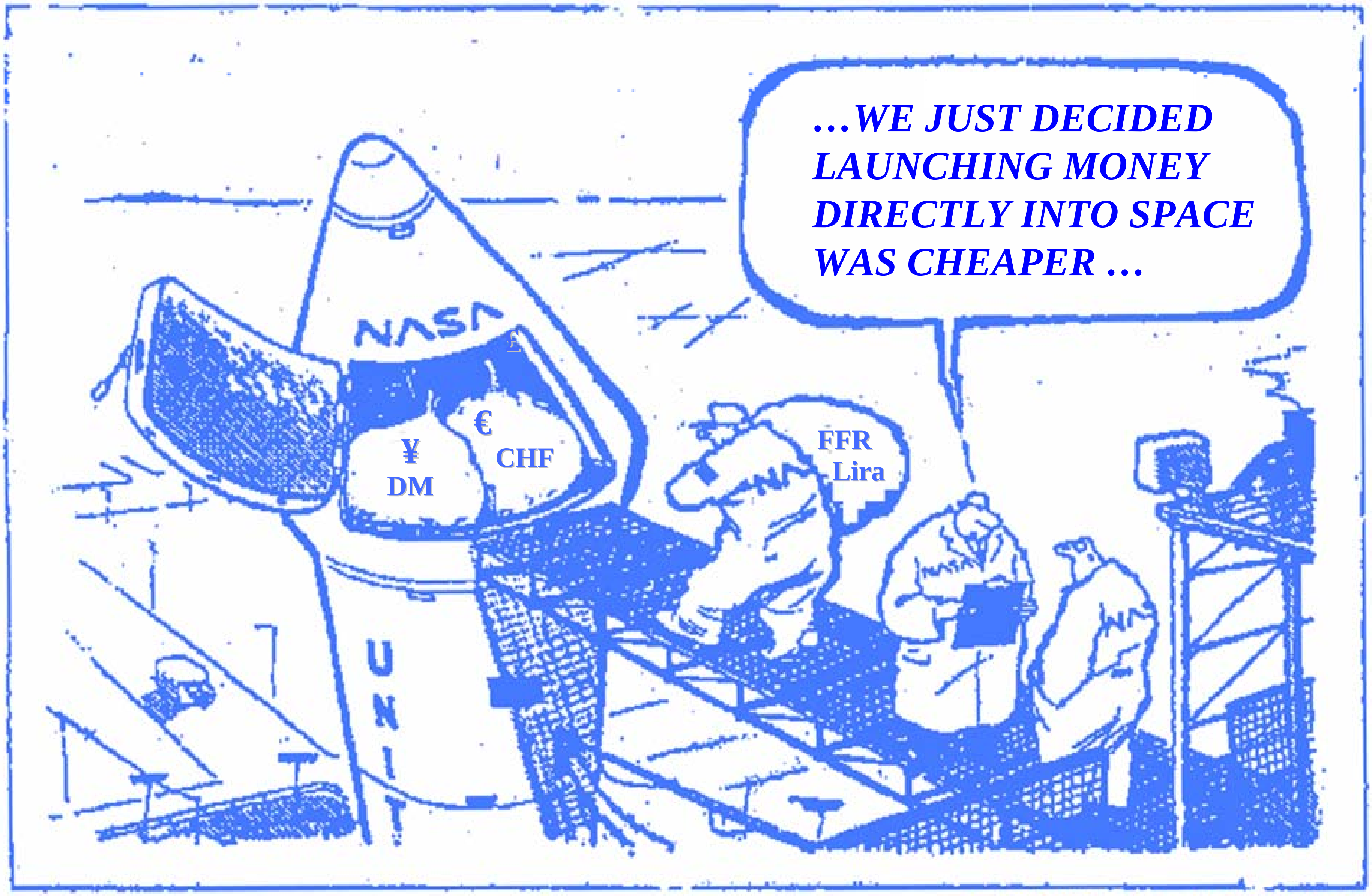


Shielding
30 tons of Magnet or
1,000 tons of material

No field
inside crew
compartment

2. Space Power Generation and Propulsion

require superconducting magnets to convert plasma into electricity as studied extensively by NASA and the Russians.



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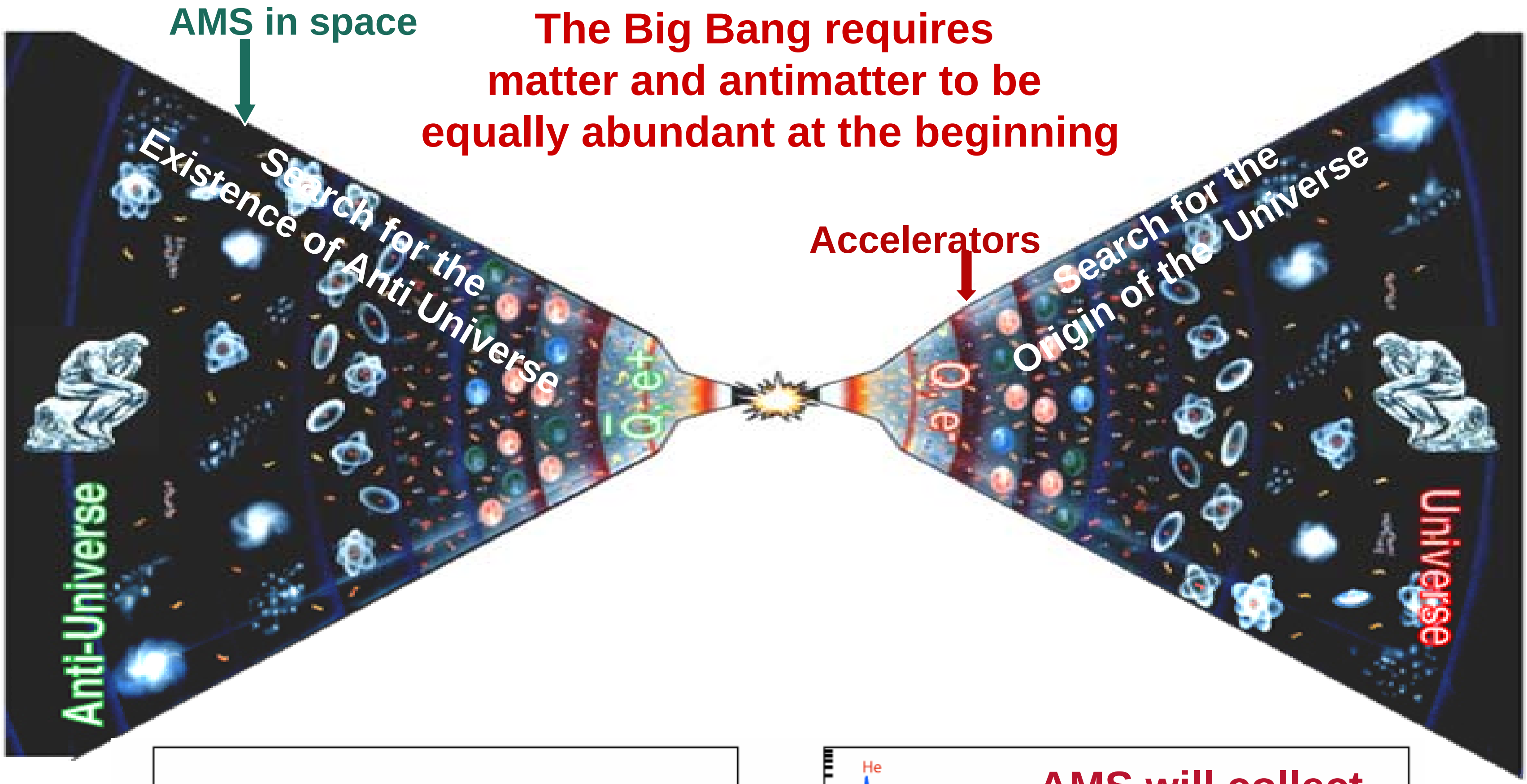
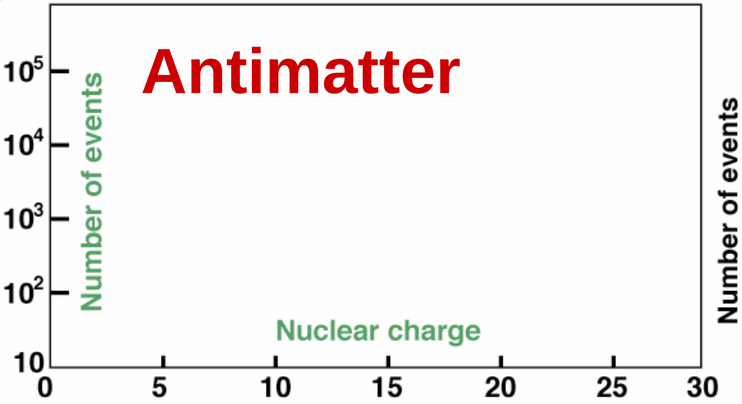
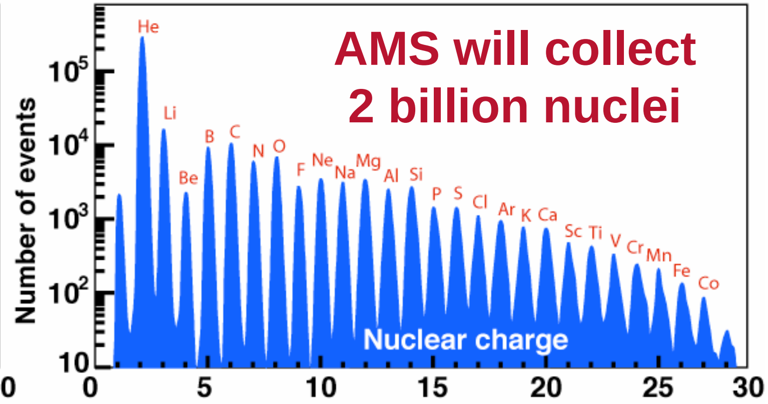
Science example: Search for antimatter

The Big Bang requires matter and antimatter to be equally abundant at the beginning






AMS will collect 2 billion nuclei

If no antimatter is found => there is no antimatter to the edge of the universe.

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Discoveries in Physics

Facility	Original purpose, Expert Opinion	Discovery with Precision Instrument
AGS Brookhaven (1960)	π N interactions	2 kinds of neutrinos, Time reversal non-symmetry, New form of matter (4th Quark)
FNAL Batavia (1970)	neutrino physics	5th Quark, 6th Quark
SLAC Spear (1970)	ep, QED	Partons, 4th Quark, 3rd electron
PETRA Hamburg (1980)	6th Quark	Gluon
Super Kamiokande (2000)	Proton Decay	Neutrino has mass
Hubble Space Telescope	Galactic Survey	Curvature of the universe
AMS on ISS	Dark Matter, Antimatter Strangelets,…	?

Exploring a new territory with a precision instrument is the key to discovery.

If you were to ask physicists,

even some of the great physicists,

to make predictions on the practical

use of a new discovery

you might hear the following:

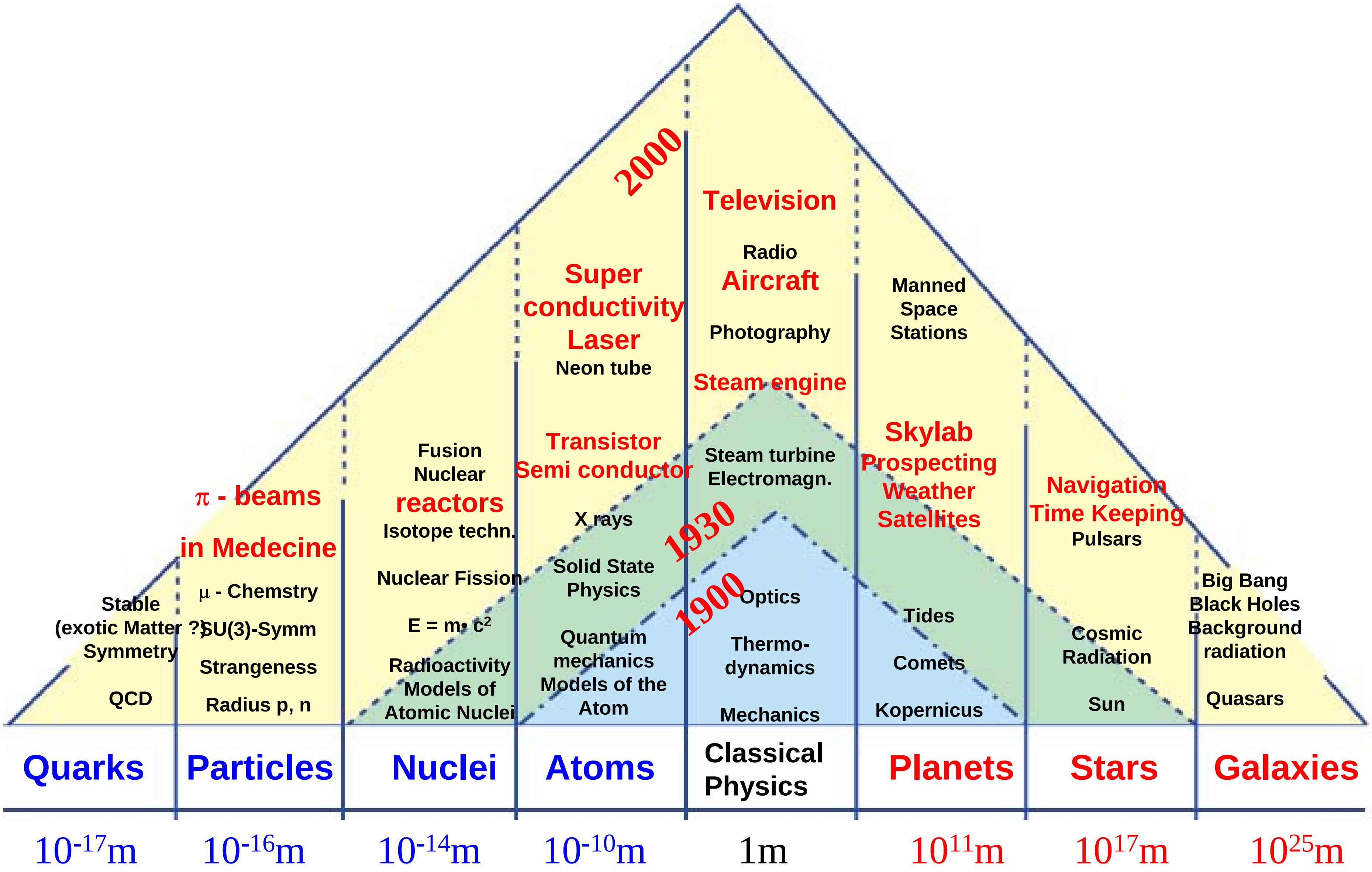
Ernest Rutherford, CA 1930 - Physicist

"The energy produced by the breaking-down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine."

Lee DeForest, 1926 - Physicist

"While theoretically and technically television may be feasible, commercially and financially I consider it an impossibility,
a development of which we need waste little time dreaming."

Lord Kelvin, CA 1880: *"X rays are a hoax."*



2000

1930

1900

Stable
(exotic Matter ?)
Symmetry
QCD

π - beams
in Medecine
μ - Chemstry
SU(3)-Symm
Strangeness
Radius p, n

Fusion
Nuclear
reactors
Isotope techn.
Nuclear Fission
$E = m \cdot c^2$
Radioactivity
Models of
Atomic Nuclei

Super
conductivity
Laser
Neon tube
Transistor
Semi conductor
X rays
Solid State
Physics
Quantum
mechanics
Models of the
Atom

Television
Radio
Aircraft
Photography
Steam engine
Steam turbine
Electromagn.
Optics
Thermo-
dynamics
Mechanics

Manned
Space
Stations
Skylab
Prospecting
Weather
Satellites
Tides
Comets
Kopernicus

Navigation
Time Keeping
Pulsars
Cosmic
Radiation
Sun

Big Bang
Black Holes
Background
radiation
Quasars

Quarks	Particles	Nuclei	Atoms	Classical Physics	Planets	Stars	Galaxies
10^{-17}m	10^{-16}m	10^{-14}m	10^{-10}m	1m	10^{11}m	10^{17}m	10^{25}m

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Lesson Five:

Most importantly:

Be curious.

Enjoy what you are doing

and

work hard to achieve your goal.