
SCIENTIFIC AMERICAN Travel
BRIGHT HORIZONS 16
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The Higgs Boson and You
Why Society Should Invest in Big Science
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# Outline of the lecture

- Some definitions
- Science and culture
- Why pure science is useful
- Big science and technology
- An example of impact on innovation

# A legitimate question

When people hear the price of big science experiments like the Large Hadron Collider or the Hubble Space Telescope they wonder what the benefits are that justify the cost.

These projects are about basic science.

Why is it worth doing?

# Some definitions

**Basic science** develop *information* to predict and perhaps explain—thus somehow understand—phenomena in the natural world.

**Formal sciences** are disciplines concerned with formal systems, such as logic, mathematics and statistics.

**Applied science** applies existing scientific knowledge to develop practical applications.

> Engineering and medical sciences are examples of applied sciences.

# Fundamental physics

**Fundamental physics** is recognized in philosophy of science as fundamental science, presumed to be more fundamental than all other sciences, such as chemistry and biology, categorized as *special sciences*.

Fundamental physics seeks universal laws expressed in mathematical language

Special sciences include laws that although accurate in "normal conditions", have exceptions.

In broad sense, fundamental physics is the analysis of nature, conducted in order to understand how the Universe behaves.

# What is big science?

**Big Science** is a term used after World War II, as scientific progress relied on **large-scale projects** usually funded by national governments or groups of governments.

The increase in **funding of big science** following the second World War was a consequence of the role that physicists played in the development of new tools and weapons, notably the radar and the atomic bomb.

The Big Science model was applied to fundamental physics (accelerators) and astronomy (telescopes), despite not related to immediate military concerns.

Towards the end of the 20th century, not only projects in basic physics and astronomy, but also in life sciences became big science, such as the Human Genome Project.

# Basic physics is big science

Can’t we do this research without increasingly more powerful accelerators and telescopes?

Aren’t there subtler ways to unveil the mysteries of Nature?

Unfortunately, to the best of our knowledge the answer to both questions is NO.

Before some unexpected breakthrough(s) happens, this tendency will remain.

# Is it so big?

## Take a look at these numbers:

| | |
|---|---|
| European Union GDP (2011) | 12.6 Trillion € |
| Fraction to R&D | 2% |
| **Total expenditure in R&D** | **250 Billion €** |
| CERN budget | 1 Billion € |
| **Total Particle Physics R&D in Europe** | **2.5 Billion € (guess)** |

Particle Physics = 1% of the total R&D in Europe

| | |
|---|---|
| Cost of LHC | 5 Billion € |
| Construction time | 10 years |
| LHC Cost/year | 500 Million € |
| European citizens | 500 Million |
| LHC cost/year/citizen | 1 € |

The LHC cost was 1€ per year during 10 years to all European citizens

# Other big projects in science

| | |
|---|---|
| The Manhattan Project | $24 billion |
| The Space projects (1957-75) | $100 billion |
| International Space Station (over 30 years) | €100 billion |
| Hubble Space Telescope (over 20 years) | $10 billion |
| Large Hadron Collider (10 years) | € 5 billion |

# Culture

Humans feel enriched by (e.g.) knowledge of the periodic table, the genetic code, how the sun works, why the sky is blue, and the expansion of Universe.

Bob Wilson (first Director of Fermilab) when asked by a Congressional Committee **"What will your lab contribute to the defense of the US?",**
replied **"Nothing, but it will make it worth defending".**

# Knowledge

Knowledge in fundamental physics and cosmology is a major component of our cultural background, with its roots in the 16th century.

Mankind as a whole should continue to explore this frontier of knowledge and can afford to do so.

# People's interest

Numerous TV documentaries, science magazines, blogs, etc, show that many people find science interesting.

**Higgs discovery impact:**

**1 billion**
Viewers of CERN video on 1,034 TV stations (5,016 broadcasts).

**496,000**
distinct connections to the seminar webcast

**136,000**
YouTube views of CMS collision animations

**17,000**
News articles written about the discovery in
**180 countries**

# Pure science is useful

I will argue that the search for fundamental knowledge motivated by curiosity, in particular in physics, is as useful as the search for solutions to specific problems.

# Basic vs. applied research

The interplay between basic knowledge, technology and products is very complex, they are all parts of highly interconnected processes.

- The linear model (from basic science to products) is too simplistic
- *"Thermodynamics owes more to the steam engine than the steam engine owes to science"*, George Porter (Nobel Laureate in Chemistry)

The time scale involved in the different steps of these processes vary widely, from several decades to several centuries.

# Paradigm change

Discovery and understanding of electricity was motivated by curiosity. In turned out that electricity brought a technological revolution.

**Paradigm change**

# Breakthroughs in pure science

The difference between basic, or pure, and applied science was illustrated by J.J. Thomson in a speech delivered in 1916:

"By research in pure science I mean research made without any idea of application to industrial matters but solely with the view of extending our knowledge of the Laws of Nature. I will give just one example of the "utility" of this kind of research, … – **I mean the use of X-rays in surgery**…

Now how was this method discovered? It was not the result of a research in applied science starting to find an improved method of locating bullet wounds. … . No, this method is due to an investigation in pure science, made with the **object of discovering what is the nature of Electricity.**"

# Discoveries with huge economic impact

The following slides reproduce citations by Casimir, a renowned theoretical physicist, and one-time Research Director of Philips.

H.G.B. Casimir, Contribution to Symposium on Technology and World Trade, US Department of Commerce, 16 November 1966.

# Transistors

"Certainly, one might speculate idly whether transistors might have been discovered by people who had not been trained in and had not contributed to wave mechanics or the quantum theory of solids.

It so happened that the inventors of transistors were versed in and contributed to the quantum theory of solids."

Quantum mechanics → Quantum theory of solids → Transistors

→ Digital electronics → Microelectronics → IT industry

**Can you imagine the economic value of quantum mechanics?**

# Computers

"One might ask whether basic circuits in computers might have been found by people who wanted to build computers.

As it happens, they were discovered in the thirties by physicists dealing with the counting of nuclear particles because they were interested in nuclear physics."

This example illustrates the fact, repeatedly seen in history, that experimentation in basic science pushes the limits of technology, which leads to new applications.

# Nuclear power

"One might ask whether there would be nuclear power because … the urge to have new power would have led to the discovery of the nucleus.

Perhaps – only it didn't happen that way."

Indeed it was an historical coincidence that the understanding of nuclear physics, making possible a nuclear bomb, occurred simultaneously to the start of World War II.

# Wireless telecommunication

"Or whether, in an urge to provide better communication, one might have found electromagnetic waves. They weren't found that way.

They were found by Hertz who emphasized the beauty of physics and who based his work on the theoretical considerations of Maxwell."

"I think there is hardly any example of twentieth century innovation which is not indebted in this way to basic scientific thought."

# Lessons from Casimir cases

- the applications of new knowledge were highly profitable;
- they were totally unforeseen when the underlying discoveries were made;
- there was a long time-lag between the fundamental discoveries and their exploitation;
- the discoverers did not get rich.

# Funding of pure science

Fundamental science should be supported by public funds

Fundamental science yield benefits which are general, rather than specific to individual products.

It generate economic returns which cannot be captured by any single company or entrepreneur.

# Is it true for today's particle physics?

Some argue that these examples are all very well, but major benefits are unimaginable from such esoteric sciences as particle physics.

This is a dangerous argument because it is too much arrogant about the imaginative power of the human mind

# Could they have imagined?

In Casimir's examples could they have imagined the future?

The answer is NO.

Researches such as those cited by Casimir were regarded as equally esoteric at the time.

Would anyone in 18$^{th}$ century invest in understanding incipient electrical sparks because he could foresee that one century later that work would lead to the understanding of electromagnetic waves and after another century to wireless telecommunications and cellular phones??!

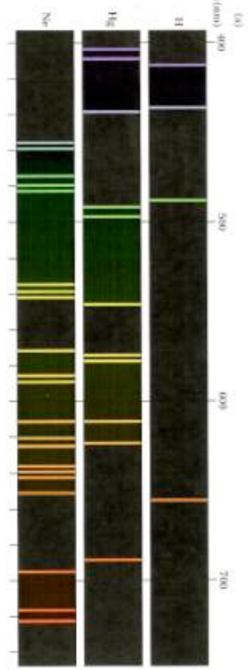
# …could they?

Imagine asking a researcher in mid 19th century studying electrical discharges in gases and measuring the light emitted, what is the practical application of this research?

Possible answers were:

- it may provide light bulbs for illumination (it did)
- it is useful to understand electrical isolation (?)

No one could have guessed that the spectral lines found in that light would inspire Bohr's atomic model and the initial development of quantic mechanics, which would be at the origin of quantum solid state physics, then the transistor, all the way up to IT industry one and half century later!



# A near miss in particle physics

If the muon (an unstable particle discovered in the 1940s) lived somewhat longer before decaying, muons could be used to catalyze nuclear fusion and generate huge amounts of energy.

(Muons are 207 times heavier that electrons; when replacing the electron in the hydrogen atom this one shrinks by a large factor; two muonic hydrogen nucleus could get much closer increasing enormously the fusion probability)

The discovery of long-lived charged particles which would catalyze fusion is not unimaginable.

# An application of antimatter

In the 30's it was found that the positron discovered by Anderson is emitted by some radioisotopes like Fluor-18 and C-11.

Latter it was found that when the positron annihilates at rest with the electron two photons with 511 keV are emitted in opposite directions.

Many decades after this phenomena found an application in a medical imaging technique called Positron Emission Tomography:

- An atom of a positron emitter is integrated in a specific molecule (tracer)
- The tracer is injected in the blood flow. The tracer molecules bind preferentially to specific cells (e.g. cancer cells).
- The emitted two-photons from many atoms, allows to reconstruct an image of the distribution of the isotope inside the body

# Speculations around the Higgs

The understanding of the true nature of vacuum may become one of the leitmotiv for research in physics in the following centuries

What is the nature of dark energy?

It is unlikely that any application emerges within my lifetime.

On the other hand I have no idea where it will lead in the long term future.

# So, what's the conclusion?

What is certainly sure, is that it
will not be possible to exploit laws and facts of nature that remain undiscovered.

Basic research will be pursued as long as humankind remains an intelligent specie.

# Practical reasons to invest in Big Science

# Education

Places like CERN are packed with young people.

These people learn new skills that later will be using in industry.

Students and graduates at CERN, ESA or NASA learn about physics, engineering and IT.

They learn to make highly complex systems working reliably.

These people are a very valuable asset in any high-tech industry.

# International cooperation

Big science is a very international activity that brings together people from different countries.

They tend to put aside national differences because what matters to them is science.

The relationships last and carry over into industry and even politics.

# Development of hi-tech industries

Building an experiment like the Large Hadron Collider requires new technologies such as superconductors, cryogenics and large-scale computing facilities.

These are subcontracted to private companies that develop new methods with applications elsewhere.

It is very hard to quantify the benefit that this brings but some estimates indicate that every **€**1 paid to industrial firms generates **€**3 of additional business.

# Spin-offs from accelerators

There are some 17,000 accelerators in the world today, of which only some 100 are used for their original purpose of research in nuclear or particle physics.

## Accelerators are being used in:

- cancer therapy
- semiconductor industry (ion implantation)
- electron beam welding and cutting
- sterilization – food, medical
- radioisotope production
- non-destructive testing
- incineration of nuclear waste
- source of synchrotron radiation } biology
- source of neutrons } solid state physics

# Spin-offs from particle detectors

Crystal detectors
- medical imaging
- security
- non-destructive testing
- research

Multi-wire Proportional Chambers
- container inspection
- research

Semi conductor detectors
- medical imaging
- many applications at the development stage

# Spin-off from informatics

World Wide Web

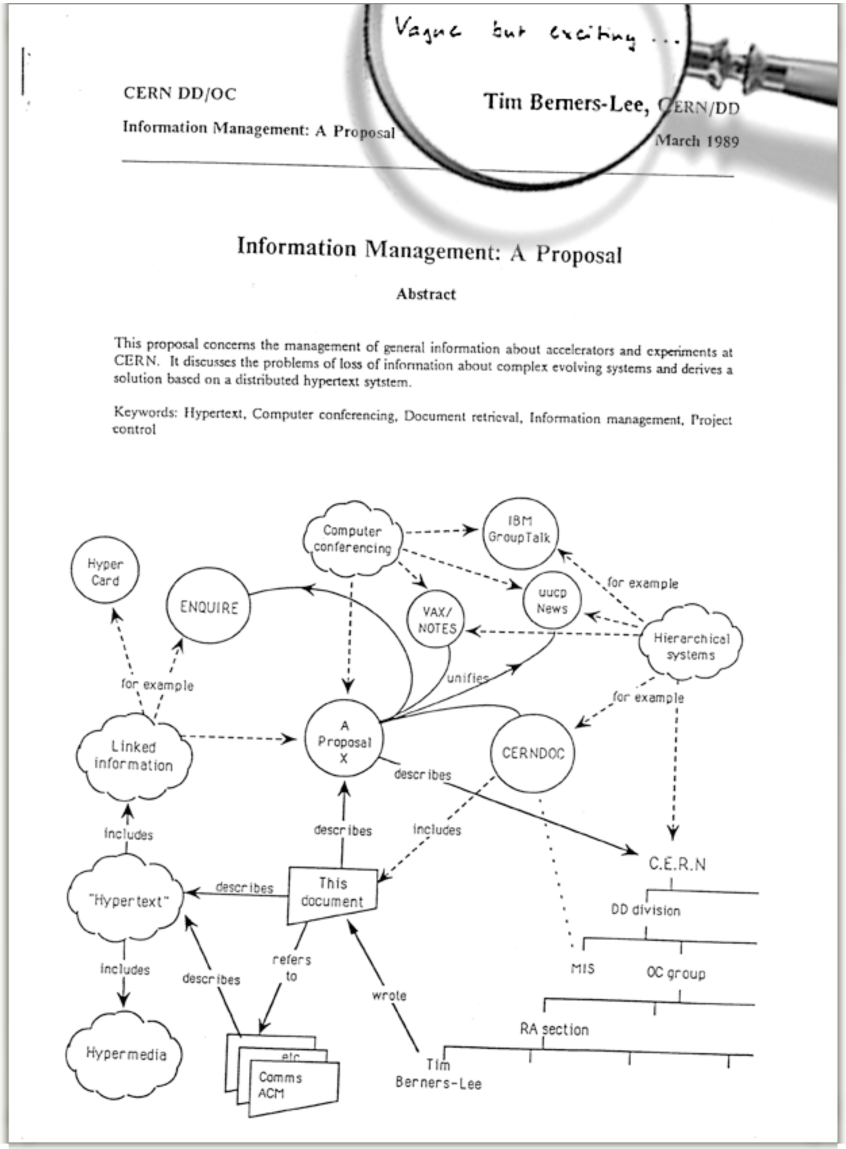
Simulation programs

Fault diagnosis

Control systems

Stimulation of parallel computing

# World Wide Web



Vague but exciting ...

CERN DD/OC

Information Management: A Proposal

Tim Berners-Lee, CERN/DD

March 1989

## Information Management: A Proposal

### Abstract

This proposal concerns the management of general information about accelerators and experiments at CERN. It discusses the problems of loss of information about complex evolving systems and derives a solution based on a distributed hypertext sytstem.

Keywords: Hypertext, Computer conferencing, Document retrieval, Information management, Project control



http://info.cern.ch (1990)



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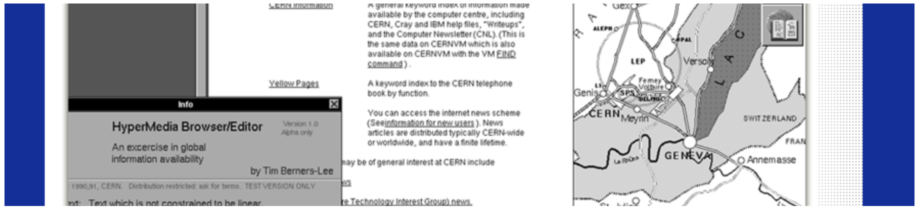
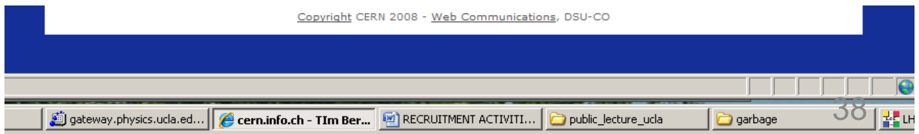




References to other information are represented like this. Double-click on it to jump to related information.

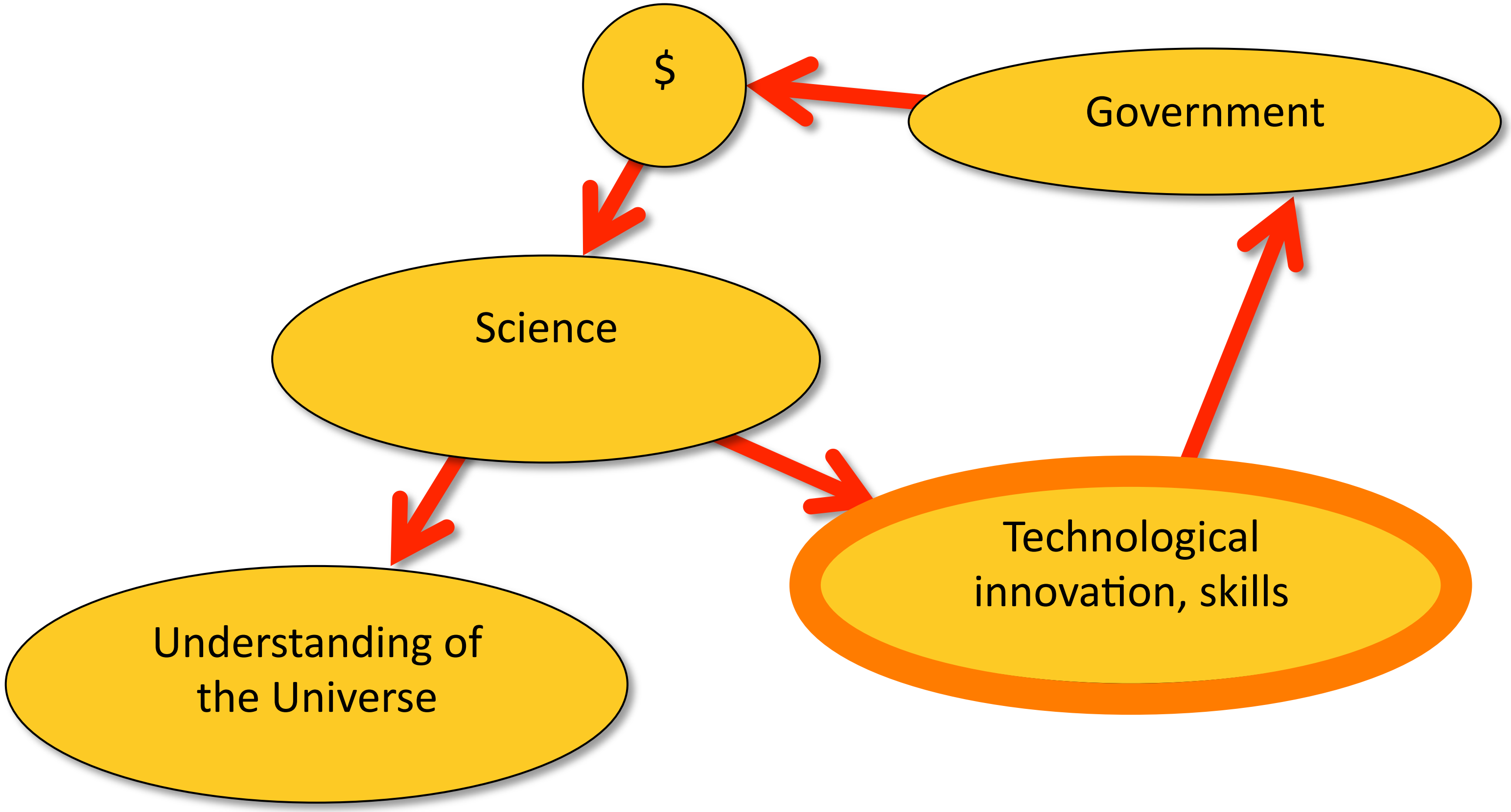


# Impact on Technology and Innovation

# The Tevatron case

John Womersley

# Why do governments support science?



# Impacts

- Can we try to measure the payoff from the investment made in the Tevatron?

- Focus on three particular areas
  – PhD students
  – Impact on SC magnet technology
  – Impact on Computing technology

# Debits

# What did the Tevatron cost?

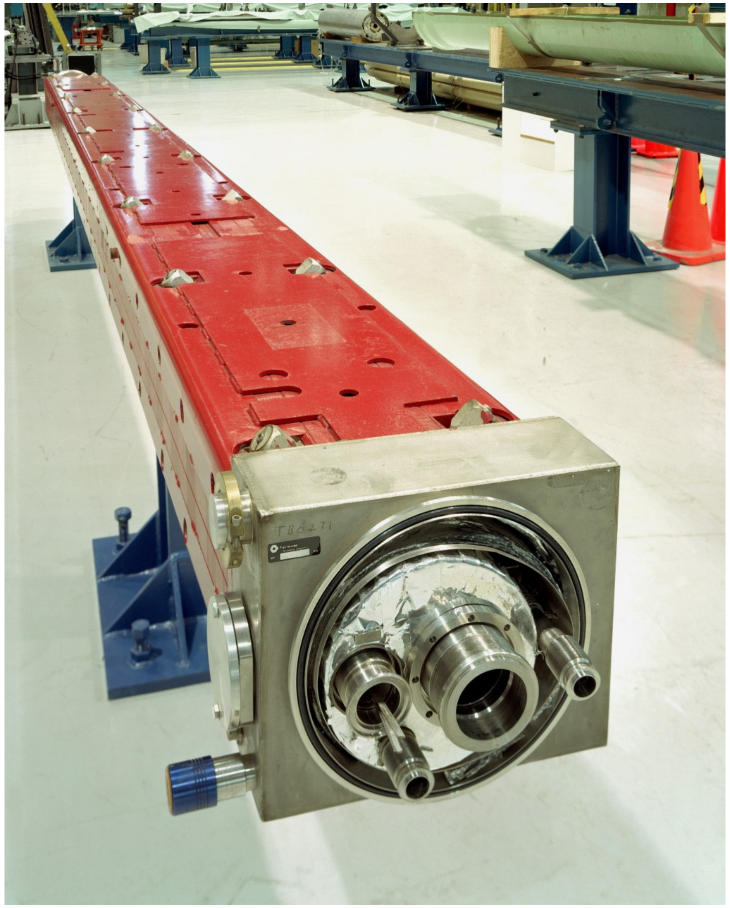
- Tevatron accelerator
  - $120M (1983) = $277M (2012 $)
- Main Injector project
  - $290M (1994) = $450M (2012 $)
- Detectors and upgrades
  - Guess: 2 x $500M (collider detectors) + $300M (FT)
- Operations
  - Say 20 years at $100M/year = $2 billion
- Total cost = **$4 billion**

# Credits

# PhD Student Training

- Value of a PhD student
  - $2.2M (US Census Bureau, 2002) = $2.8M (2012 $)
- Number of students trained at the Tevatron
  - 904 (CDF + DØ)
  - 492 (Fixed Target)
  - 18 (Smaller Collider experiments)
  - 1414 total
- Financial Impact = **$3.96 billion**

# Superconducting Magnets



Tevatron was the first installation of mass-produced superconducting magnets on an industrial scale

# Superconducting Magnets

- Current value of SC Magnet Industry
  - $1.5 Billion p.a.
- Value of MRI industry (major customer for SC magnets)
  - $5 Billion p.a.
- This industry would probably have succeeded anyway – what we can realistically claim is that the large scale investment in this technology at the Tevatron significantly *accelerated* its development
  - Guess – one to two years faster than otherwise?
- Financial Impact = **$5-10 billion**

# Computing – Linux PC farms

- Computing requirements led to pioneering adoption of PC Farms running Linux for large scale data handling.

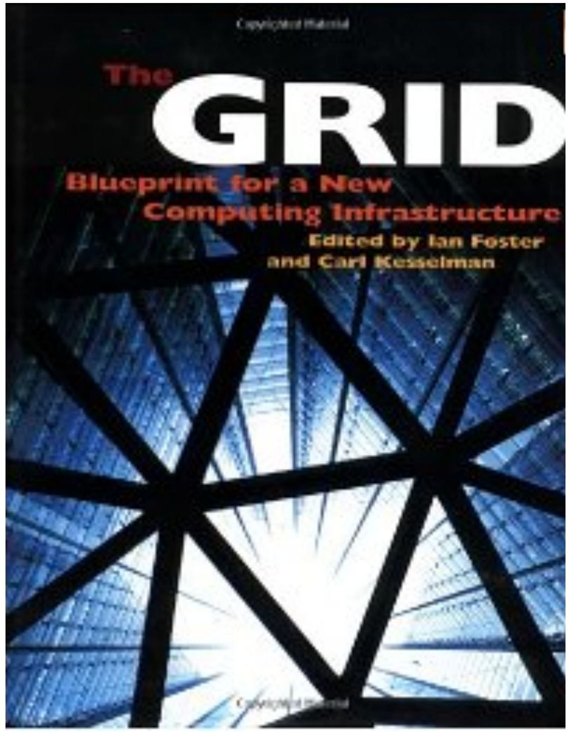
- More than 90% of the world's supercomputers now use Linux.

# Distributed Computing

Concept of Computing as a Utility

  “The Grid” (1998)

Grid resources was used for data analysis of the Tevatron experiments



# Cloud Computing


Remotely accessible Linux farms are now a commercial service

- Amazon etc.

# Cloud Computing

- Value of Cloud Computing Industry today
  - $150 Billion p.a. (Gartner)
- This industry would definitely have succeeded anyway – but let’s assume that the stimulus given by the Tevatron experiments gave just a *3 month* speed-up to its development
- Financial Impact = **$40 billion**

# Balance sheet

| | |
|---|---|
| • 20 year investment in Tevatron | - $4B |
| • Students | $4B |
| • Magnets and MRI | $5-10B |
| • Computing | $40B |
| | ~ $50B total |

It is plausible that the Tevatron has returned its investment roughly tenfold over its lifetime

# Final remarks

Basic science has many basic motivations: human, philosophical, sociological, technological, economic.

Basic physics requires important, but not outrageous, resources. Our society has the means to afford it.

Scientists and science must be accountable to society. It is the best way to guarantee good science.