Potential Scientific Contributions

Feb. 25, 2010

30 Standard Model Charts Available
Suitable for lamination
One per family, please
Answers to last week’s questions

• Erratum: Proton bunch is \( \sim 16 \) microns (\( \mu \text{m} \)) (down from a mm) at collision point; human hair is 50 microns.

• The SSC was to be 20 TeV on 20 TeV; 54 miles (90 km) in circumference; \( \sim 6 \) T magnets; 
  \( 10^{33} \text{ cm}^{-2} \text{ sec}^{-1} \); \( 10^{34} \text{ cm}^{-2} \text{ sec}^{-1} \).
Answers to last week’s questions

Rest Mass of Proton is $1.67 \times 10^{-27}$ kg or 0.938 GeV/c$^2$, or ~1 GeV

<table>
<thead>
<tr>
<th>Kinetic Energy of proton</th>
<th>Speed (% c)</th>
<th>Accelerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Ion source</td>
</tr>
<tr>
<td>0.05 GeV</td>
<td>31.4</td>
<td>Linac 2</td>
</tr>
<tr>
<td>1.4 GeV</td>
<td>91.6</td>
<td>PS Booster</td>
</tr>
<tr>
<td>25 GeV</td>
<td>99.93</td>
<td>PS</td>
</tr>
<tr>
<td>450 GeV</td>
<td>99.9998</td>
<td>SPS</td>
</tr>
<tr>
<td>7,000 GeV</td>
<td>99.999999</td>
<td>LHC</td>
</tr>
</tbody>
</table>

$E = K.E. + \text{rest energy}$

$E = mc^2 = m_0c^2/(1 - v^2/c^2)^{1/2}$
Topics

Finish up LHC detectors: CMS, ALICE (quark-gluon plasma); LHCb
Computational science: challenges of the GRID and Data handling
The Higgs Boson (source of mass)
Supersymmetry and String Theory (guest speakers)
Relation to Cosmology (guest speaker)
Importance of Basic Research
Closing Speculations
Topics

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Four Main Detectors

ATLAS

CMS

ALICE

LHCb

Really Big

Just Big
The CMS - Compact Muon Solenoid - Detector
Compact Muon Solenoid

[Diagram of the Compact Muon Solenoid (CMS) with labels]

- Total weight: 12500 T
- Overall diameter: 15.0 m
- Overall length: 21.5 m
- Magnetic field: 4 Tesla

Components:
- CMS
- Tracker
- Crystal ECAL
- Superconducting Magnet
- Return Yoke
- HCAL
- Feet
- Muon Chambers
- Preshower
- Forward Calorimeter
The Systems of CMS

About CMS
A CMS Disc

400 metric tons

Earth
100 m up

Cathedral size cavern
CMS – Virtually Live

Balcony-eye view

Beam pipe into CMS

Floor view

Floor view, later

Front, close to completion
The CMS control room

Underground, near where the action is
Simulated Success: What the Higgs would look like if found in CMS:
A Large Ion Collider Experiment i.e. the ALICE Detector

Virtual View

Size: 26 m long, 16 m high, 16 m wide
Weight: 10 000 tonnes
Design: central barrel plus single arm forward muon spectrometer
Location: St Genis-Pouilly, France.
The Quark/Gluon Plasma

A simulation
~ 1 min 20 sec

A plasma is a hot, ionized gas and is the fourth state of matter (i.e solid, liquid, gas, plasma)
Large Hadron Collider beauty (LHCb) Detector

Size: 21m long, 10m high and 13m wide
Weight: 5600 tonnes
Design: forward spectrometer with planar detectors
Location: Ferney-Voltaire, France.
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Importance of Basic Research

Closing Speculations
The Third Leg of Science

Theory
Experiment
Computation
Simulation
GRIDS
For example, the US Open Science Grid

A US GRID

Physics
Biology & Medicine
Chemistry
Video: intro to the GRID

The LHC GRID
~ 5 minutes
Advantages of GRID Computing

• Insurance against data loss
• Efficiencies of scale
• No single point failure
• Costs are distributed and shared
• The death of distance: innovation is local
• Inherent flexibility and adaptability
Data Handling Challenge

- ATLAS will produce 320 MB/s
- CMS will produce 220 MB/s
- LHCb will produce 50 MB/s
- ALICE will produce 100 MB/s

15 PB – PetaBytes – 1500 Trillion Bytes – $10^{15}$ bytes per year, or ~2 trillion CDs per year at 700MB per CD!
The US Tier 1 Centers: Fermilab
US Tier : BNL

BNL on BNL TIER 1

~ 3 min
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Higgs Mechanism

• How Mass is acquired
  – Higgs Field – the Mechanism
  – Higgs Boson – a force carrying particle
Higgs Mechanism
Higgs Mechanism
Higgs Mechanism
Higgs Boson
Higgs Boson
Higgs Video

Just when you think the Higgs couldn't be explained better . . .
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Closing Speculations
Supersymmetry
String Theory
String Theory in 2 x (2 Minutes)

• **String theory is simple**

• **Another, more scientific view**
String Theory in 9 Minutes

Guest Interviewee
Unification of Forces

Forces Merge at High Energies

Energy in GeV

Strength of Force

strong
weak
electromagnetic

Unification

$10^{28}$ eV
Planck Scale

String Theory
Unification of Forces
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Importance of Basic Research
Closing Speculations
History of the Universe
(as seen by an Astronomer)
History of the Universe
(as seen by a particle physicist)
T = 13 billion years
Stars, Galaxies, Life, You & Me
History of the Universe

T = 13 billion years
Stars, Galaxies, Life, You & Me

T = 300,000 years
Electrons, Nuclei, radiation
History of the Universe

- $T = 13$ billion years
  - Stars, Galaxies, Life, You & Me

- $T = 300,000$ Years
  - Electrons, Nuclei, radiation

- $T = .0001$ sec
  - Electrons, Quarks, Gluons, Radiation

Key:
- $W, Z$ bosons
- q quark
- g gluon
- e electron
- $\mu, \tau$ tau
- $\nu$ neutrino
- photon
- meson
- galaxy
- baryon
- star
- ion
- atom
- black hole

Particle Data Group, LBNL, © 2008. Supported by DOE and NSF
**History of the Universe**

- **T = 13 billion years**
  - Stars, Galaxies, Life, You & Me

- **T = 300,000 years**
  - Electrons, Nuclei, Radiation

- **T = .0001 sec**
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**Key:***
- W, Z bosons
- Photons
- Quarks
- Gluons
- Electrons
- Muons
- Neutrinos
- Black holes
- High-energy cosmic rays
- Accelerators
- LHC, Tevatron, RHIC

**Particle Data Group, LBNL, © 2008. Supported by DOE and NSF**
Need for Light on the Dark...
An Expert’s Explanation:

**Special guest and virtual presenter**

~ 16 minutes
“... And the “size scale” continues to collapse, as the study of the largest things of which we know is found to have more and more in common with the study of the smaller things of which we know.”

-- NAS Report, a Space Program Worthy of a Great Nation, 2009

Oroborus

The Most Important Product of Knowledge is Ignorance (of what we don’t know), Informed & Intelligent -- David Gross
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Importance of Basic Research

Closing Speculations
What’s the Use of Basic Research?

Basic Science [i.e. knowledge]—motivated by curiosity; responsibility of governments

Strategic – directed, both government & industry

Applied – designed to answer specific questions; industry

Spin-offs and Stimulation of industries

• Accelerators
  ➔ Cancer therapy; medicine
  – Semiconductor industry
  – Sterilization of food, medical, sewage
  – Radiation processing
  – Non-destructive testing
  – Incineration of nuclear wastes
  – Synchrotron radiation – biology, materials,
  – Neutron sources – biology, materials
Spin-offs and Stimulation of industries

• Particle detectors
  – Crystal detectors
    • Medical imaging
    ➔ Security
    • Non-destructive testing
    • Research
  – Multi-wire proportional chambers
    • Container inspection
  – Semiconductor detectors
    • Pixels in cameras, flat panel TVs, etc
Spin-offs and Stimulation of industries

- **Informatics**
  - World Wide Web
  - Simulation programs
  - Fault diagnosis
  - Control systems
  - Simulation by parallel computing
  - Data base mining

- **Superconductivity**
  - Magnets for MRI scanners (a.k.a. NMR)
Spin-offs and Stimulation of industries

- Nano-revolution comes from synchrotron radiation, formerly a waste product
- What is synchrotron radiation, what it can do at LCLS ~ 6 min
Basic Research: What’s the Use?

• Education:
  – Problem solving skills, learn by doing
  – Networking, real and virtual
  – Transfer to other fields, e.g. finance
What’s the use of Basic Research?

• Culture
  – Congress; “What will your lab [Fermilab] contribute to the defense of the US?”; Bob Wilson: “Nothing, but it will make it worth defending.”
  – Silicon Valley ➔ MIT + Entrepreneur; Stanford + Entrepreneurs

• Economists:
  – As an investment: Mansfield, 1991: ROR = 28%
  – Robert Solow, 1987 Nobel Address: “technology remains the dominant engine of growth, with human capital investment in second place.”

• A Certainty: not possible to exploit new laws & facts of nature if remain undiscovered.
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Closing Speculations
History as a guide

- Gladstone: “What use is electricity?”
  Faraday: “One day Sir you may tax it.”
- Lord Kelvin: “There is nothing new to be discovered in physics now. All that remains is more and more precise measurement.”
- Rutherford: “Anyone who expects a source of power from the transformation of atoms is talking moonshine.”
- DNA -- Atomic Energy Commission, then DOE: radiation effects on biology
- Climate change – AEC & DOE: atmospheric fallout
Organizational Vanguard?

• CERN is a unique, truly international Laboratory

• Adventures in the sociology of large science: ATLAS, CMS, LHCb, etc

• Future of Science: inevitably international?
## Financing (2009 budget)

<table>
<thead>
<tr>
<th>MC</th>
<th>Contribution %</th>
<th>MCHF</th>
<th>MEuros</th>
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<tbody>
<tr>
<td>Germany</td>
<td>19.88</td>
<td>218.6</td>
<td>144</td>
</tr>
<tr>
<td>France</td>
<td>15.34</td>
<td>168.7</td>
<td>111.2</td>
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<tr>
<td>UK</td>
<td>14.7</td>
<td>161.6</td>
<td>106.5</td>
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<tr>
<td>Italy</td>
<td>11.51</td>
<td>126.5</td>
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<td>8.52</td>
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<tr>
<td>CH</td>
<td>3.01</td>
<td>33.1</td>
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<tr>
<td>Poland</td>
<td>2.85</td>
<td>31.4</td>
<td>20.7</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>1096.6</td>
<td>724</td>
</tr>
</tbody>
</table>
On the side of history?

- Large Science projects are indispensable to the health and vitality of U.S. science
- LHC, ITER – Big Science gone Global – require long-term commitments
- Science Research is a de facto international enterprise
- Many of the best research facilities are now outside the U.S.

Report to the President and Congress on Large Science Projects, DOE, 1996
Take Home Messages?

• The only reliable prediction of scientific advancement seems to be that it is unpredictable, & well beyond our current imagination and perception of physical Reality.
• Science progress requires big facilities. Big facilities require cooperation to be effective.
• We are learning real time about the consequences of informatics, e.g. GRID, instant global communications, etc.
• Fundamental, forefront physics advancement today & tomorrow requires collaboration and sustained, serious investments on the part of Governments and other funding sources.
• Economic spin offs tend to be immense, but are not the proper motivation for the funding science. The Science is.
Web References

An overview of physics: David Gross, the Coming Revolutions in Theoretical Physics
http://www.youtube.com/watch?v=AM7SnUl w-DU
http://www.particleadventure.org/
http://public.web.cern.ch/public/
http://hands-on-cern.physto.se/hoc_v21en/index.html
BACK UP
Future: supersymmetry and string theory

- http://www.youtube.com/watch?v=AM7SnUlw-DU

- David Gross lecture
A pro explains GUTs

Universe

Evolution of the Universe

The Universe began with a “Big Bang” about 15 billion years ago.

- 15 billion years
- 1 billion years
- 1 million years
- 300,000 years
- 3 minutes
- 1 second

- Quark "soup" matter dominates
- Neutrons and protons formed
- Helium nuclei formed
- Microwave background radiation fills universe
- Stars and galaxies exist, atoms form

10^{-10} s
10^{15} deg
10^{10} deg
10^9 deg
6000°
4000°

What is the matter? . . . . Where is the antimatter?
History of the Universe
lumpiness
Dark Matter
Dark Energy
CERN – Conseil Européen pour la Recherche Nucléaire
From original 11 to 20
Organization

CERN Council

- Scientific Advisory Committee
- Director General
- Finance Committee
US Role in LHC

• LHC Machine -- $200M, in kind, DOE, capped

• LHC Detectors -- $250M, in kind, DOE; $81M from NSF, capped
  – Best efforts,

• Observer, not a Member
U.S. LHC Machine Contribution
U.S. Collaborating Institutions: >1700 scientists, engineers, grad students
US ATLAS

- 700 physicists, engineers, grad students
- 44 institutions (BNL host national lab, mostly universities)
- The whole ATLAS collaboration includes 2900 physicists from 37 countries and 169 institutions.
- Tracking systems (pixel, semiconductor and transition radiation tracker); Calorimeters (Liquid Argon Calorimeter, Tile Calorimeter); Muon Spectrometer
- Data Acquisition and Computing
US CMS

- 49 institutions, 430 Ph.D. physicists, ~ 200 graduate students, & > 300 engineers, technicians, and computer scientists
- 3000 scientists and engineers; 83 institutes in 38 countries, spanning Europe, Asia, the Americas and Australasia.
- US working on Hadron & Electromagnetic Calorimeters; Muon Detector; Silicon Strip Tracking system; Forward Silicon Pixel Tracking System; Trigger System and Data Acquisition
- Computing
Questions for the Universe

Discoveries at the Large Hadron Collider promise to revolutionize our understanding of the universe. The LHC experiments could reveal answers to many of the most profound questions of the physical world.

1. Are there undiscovered principles of nature?
2. How can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Do all the forces become one?
5. Why are there so many kinds of particles?
6. What is dark matter?
7. How did the universe come to be?
8. What happened to the antimatter?

National Science Foundation
Interview with Head of CERN IT

• http://cdsweb.cern.ch/record/1129134

• ~ 7 min
Grid Computing

http://www.gridcafe.org/version1/openday/Whatishis.html
Tie in to Cosmology

On the side of history?

• Fundamental physics is now centered at CERN
• Does computer linkages (and English) make geography irrelevant?
• Is globalization inevitable in science?
• Is the US prepared for 21st century science?
  – US has been an unreliable Big Science Partner
  – US STEM education is problematical
  – US industry “outsourcing” to other countries