www.vlhc.org
Design Study for a Staged Very Large Hadron Collider
Very Large Hadron Collider
This design study of a staged VLHC showed us that:

- A staged VLHC starting with 40 TeV and upgrading to 200 TeV in the same tunnel is completely feasible.
- There are no major accelerator physics or technical obstacles.
- The cost of the first stage of the VLHC is comparable to that of a linear electron collider.
- There are many opportunities to decrease the cost through R&D and engineering studies.
- The VLHC fits into and should be considered part of a rational worldwide high-energy physics plan that includes a linear electron collider.
The Presentation to the Fermilab AAC

The order of the presentation:

- Introduction and description of the concept
  - P. Limon

- Accelerator physics for Stage 1 and Stage 2 VLHC
  - M. Syphers

- Stage 1 VLHC systems and technology
  - G. W. Foster

- Conventional construction
  - P. Garbincius

- Cost analysis, R&D, and future needs
  - P. Limon
Finding The Right Plan for High-Energy Physics

- The right plan will match the tools we build to the physics we seek to understand.

- The right plan will have a vigorous program to develop new and better accelerators and experiments.

- The right plan will be a coordinated worldwide plan, with every region represented and involved intellectually and financially.
The Tools of High-Energy Physics

- Precision measurements
  - Lepton colliders are used to make precision measurements of known spectroscopy.

- Anomalies
  - Specialized accelerators, beams and experiments illuminate the dark side, such as neutrino mass, CP violation, particle cosmology, etc.

- Big discoveries
  - Very-high-energy hadron colliders probe deep into the unknown and make discoveries at the energy frontier.
The Energy Frontier

- The most exciting physics is at the energy frontier
  - Someone, somewhere will advance to the next energy scale. It will happen.
  - A hadron collider is the only sure way to the next energy scale.
  - The technology of the VLHC is available to us now.
  - Our plan for a staged VLHC makes the energy frontier both affordable and achievable.
A Staged VLHC

- Stage 1 VLHC, 40 TeV collision energy, has about the same cost as a linear collider at 500 GeV.
- The VLHC is much cheaper per unit parton energy.
- The VLHC can be upgraded to 200 TeV.
- The VLHC will define the energy frontier for 50 years.

- A linear collider may have some nice physics (we don't know that yet), but it will never be at the energy frontier.
- If we can afford a linear electron collider, we can afford a VLHC.
The Concept

- Take advantage of the space and excellent geology near Fermilab.
  - Build a **BIG** tunnel.
  - Fill it with a “cheap” collider.
  - Later, upgrade to a higher-energy collider in the same tunnel.

This spreads the cost and produces exciting energy-frontier physics at each step.

It allows more time for the development of cost-reducing technologies and ideas for the challenging high-energy upgrade.

A high-energy full-circumference injector into the high-field machine solves some sticky accelerator issues, like field quality at injection.

A **BIG** tunnel is reasonable for advancing to a synchrotron radiation-dominated collider.
The first step

A VLHC Accelerator Study

- Requested and charged by the Fermilab Director
- Based on a Staged Scenario of $E_{cm} > 30$ TeV, $Lum > 10^{34}$ first, eventually $E_{cm} > 150$ TeV, $L_{peak} > 2 \times 10^{34}$ in the same tunnel.
- The report is due in May, 2001.
- The Report will include estimates of the ranges of expected costs and some analysis of the major cost drivers for Stage 1. **But it is not a cost estimate for Stage 1 of a VLHC!**
- BNL and LBNL are involved, particularly in accelerator physics, vacuum systems and feedback.
- We will have international involvement; initially as reviewers, which will be the first step toward forming an international collaboration.
The VLHC Design Study Group

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May 21, 2001

Fermilab Accelerator Advisory Committee

P. Limon

Intro
Preliminary Review

A preliminary review was held April 30, May 1, 2001, as a check to see if we were way off base before releasing our report.

- **Review Committee:**
  - Bob Kephart, Fermilab, Chairman
  - Gerry Dugan, Cornell; Jon Ives, consultant; Eberhard Keil, CERN
  - Philippe Lebrun, CERN; Al Zeller, MSU; Erich Willen, BNL;
  - Mike Anerella, BNL

The reviewers made many good recommendations and observations. They found no serious insurmountable accelerator physics issues. They recognized the need for some cost- and risk-reducing R&D.

**Question:** “Have the major cost drivers been identified and is the preliminary cost estimate for Stage 1 of the VLHC reasonable?”

**The Reviewers’ Answer:** “Although they can and will be improved through focused R&D, the basic technologies on which the Stage 1 VLHC rests are known today. The unit costs quoted to support the estimates can be deemed as rather conservative.”
Advantages of Staging

- Each step yields new and interesting physics.
- Stage 1 is at or close to the minimum cost for 40 TeV and its construction greatly reduces the cost of Stage 2.
- It is sited at an existing lab and thus uses the existing intellectual and organizational infrastructure, saving both time and money.
- There are many accelerator physics advantages. For example:
  - A superferric magnet permits injection from Tevatron.
  - Injection at high energy eliminates magnetization and stability issues in the high-energy collider.
  - The initial technology is straightforward, minimizing risk and necessary R&D, and allowing an early start.
  - Staging makes time available for the R&D necessary to solve problems and reduce cost of high-energy phase

- Using the Fermilab (or CERN! or DESY!) existing accelerator complex saves at least $1 billion
Disadvantages of Staging

- It may take longer to get to the highest energy. This is more a political and cost issue than a technical one.
- There may be other scenarios that get to high energy sooner.
  - For example, one could get to an intermediate energy, say 100 TeV, by skipping 2 T magnets and using 5 T for the first step. This might be quicker, although at Fermilab it would require a new injector.
- The initial low-energy design must predict correctly many details of the final high-energy design.
- There will necessarily be a pause in the HEP program while the second collider is installed in the tunnel (five to seven years).
- The plan starts with a very big tunnel, which will have some political difficulties.
Staged VLHC Ring Layout

- Fermilab cluster: Injection, Extraction, RF, Two Detectors
- Typical Stage 1 Surface Facility for Cryogenics (1 of 6)
- Far Cluster LF -> HF Transfer and Collimation
- Ring Orientation Arbitrary

Not to scale

~20 km

Stage 1

Required for Stage 2
## Very Large Hadron Collider

<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Circumference (km)</td>
<td>233</td>
<td>233</td>
</tr>
<tr>
<td>Center-of-Mass Energy (TeV)</td>
<td>40</td>
<td>175</td>
</tr>
<tr>
<td>Number of interaction regions</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Peak luminosity (cm(^{-2}\text{s}^{-1}))</td>
<td>(1 \times 10^{34})</td>
<td>(2.0 \times 10^{34})</td>
</tr>
<tr>
<td>Luminosity lifetime (hrs)</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>Injection energy (TeV)</td>
<td>0.9</td>
<td>10.0</td>
</tr>
<tr>
<td>Dipole field at collision energy (T)</td>
<td>2</td>
<td>9.8</td>
</tr>
<tr>
<td>Average arc bend radius (km)</td>
<td>35.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Initial Number of Protons per Bunch</td>
<td>(2.6 \times 10^{10})</td>
<td>(7.5 \times 10^{9})</td>
</tr>
<tr>
<td>Bunch Spacing (ns)</td>
<td>18.8</td>
<td>18.8</td>
</tr>
<tr>
<td>(? \text{ at collision (m)})</td>
<td>0.3</td>
<td>0.71</td>
</tr>
<tr>
<td>Free space in the interaction region (m)</td>
<td>(\pm 20)</td>
<td>(\pm 30)</td>
</tr>
<tr>
<td>Inelastic cross section (mb)</td>
<td>100</td>
<td>133</td>
</tr>
<tr>
<td>Interactions per bunch crossing at (L_{\text{peak}})</td>
<td>21</td>
<td>58</td>
</tr>
<tr>
<td>Synchrotron radiation power per meter (W/m/beam)</td>
<td>0.03</td>
<td>4.7</td>
</tr>
<tr>
<td>Average power use (MW) for collider ring</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Total installed power (MW) for collider ring</td>
<td>30</td>
<td>250</td>
</tr>
</tbody>
</table>
Stage 2

☞ It is clear that Stage 2 could get to 200 TeV or higher!

<table>
<thead>
<tr>
<th>Collision Energy (TeV)</th>
<th>Magnetic Field (T)</th>
<th>Leveled Luminosity (cm(^{-2})s(^{-1}))</th>
<th>Optimum Storage Time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1 40</td>
<td>2</td>
<td>1.0 x 10(^{34})</td>
<td>20</td>
</tr>
<tr>
<td>Stage 2 125</td>
<td>7.1</td>
<td>5.1 x 10(^{34})</td>
<td>13</td>
</tr>
<tr>
<td>Stage 2 150</td>
<td>8.6</td>
<td>3.6 x 10(^{34})</td>
<td>11</td>
</tr>
<tr>
<td>Stage 2 175</td>
<td>10</td>
<td>2.7 x 10(^{34})</td>
<td>8</td>
</tr>
<tr>
<td>Stage 2 200</td>
<td>11.4</td>
<td>2.1 x 10(^{34})</td>
<td>7</td>
</tr>
</tbody>
</table>

Leveled luminosity vs. energy. The luminosity is limited by one or more of the beam-beam tune shift, the synchrotron-radiation power per meter, or the debris power in the interaction region.
Stage 1 magnet

Cryogenic services

Stage 2 magnet

Electronics Module

R 72 in

Ø26.00 in

Ø24.00 in

Ø8 in

Ø6 in
VLHC Stage 1 Magnet

Cross-section of Stage 1 superferric magnet 100 kA superconducting transmission line
VLHC
Generalized Geologic Section
228 km Ring
North of Fermilab
Stage 1 Issues

- Dynamic aperture seems not to be an issue.
- Beam stability at injection needs study. It appears that it can be controlled by straightforward methods, but experiments need to be done to verify this.
- Is this the best way to proceed? How does it compare with other staging options or a no-staging option? A subject for Snowmass.
- The cost analysis results are still uncertain. Continued engineering studies will narrow the uncertainties of the cost analysis.
- What are the public acceptance issues?
- What R&D remains?
Public Acceptance

 Fet We must work on public acceptance from the beginning.

 Goddess The old way of “decide, announce, defend” will not work.

 What are the possible public acceptance issues?
 1. risk to environment, safety and health;
 2. effects on property values;
 3. distrust of government;
 4. esthetics;
 5. perceived lack of community control;
 6. appropriate use of government funds;
 7. community disruption during construction;
 8. perceived lack of participation in decision-making;
 9. trust of Fermilab.

 There will be a group studying this issue at Snowmass.
Technical Conclusions of the Study

- There are no serious technical obstacles to the Stage 1 VLHC, although there are improvements and cost savings that can be gained through a vigorous R&D program.

- The Stage 2 VLHC can reach 200 TeV and $2 \times 10^{34}$ or more in the 233 km tunnel. There is the need for magnet and vacuum R&D, but no insurmountable problems. The luminosity limits are multiple interactions, IP power and luminosity lifetime.

- Making a large tunnel is possible in the Fermilab area. Managing such a large construction project will be a challenge.

- A total construction time of 10 years is feasible, but the logistics will be complex.