Summary

- You've heard the details that convinced us that the VLHC is technically feasible and has great physics discovery potential.

- Next:
  - A summary view of the cost analysis. The VLHC is affordable.
  - An R&D plan, including Stage 2 challenges
  - How the VLHC fits smoothly into an international plan with a linear electron collider
  - What we are asking of the Subpanel

VLHC Cost Basis

- **Used only the "European" cost base**
  - No detectors (2 halls included), no EDI, no indirects, no escalation, no contingency – a "European" base estimate. This is appropriate for cost comparisons, as the factors needed to make it a "US estimate" apply to all projects in the same manner.
- **Estimated the cost drivers using a standard cost-estimating format. This is done at a fairly high level.**
  - Underground construction (Estimates done by AE/CM firm)
  - Above-ground construction (Estimates done by FNAL Facility Engineering Section)
  - Arc magnets
  - Corrector and special magnets (injection, extraction, etc)
  - Refrigerators
  - Other cryogenics
  - Vacuum
  - Interaction regions
- **Used today's prices and today's technology. No improvements in cost from R&D are assumed.**

VLHC Cost Drivers

In FY2001 K$	VLHC Estimate	VLHC Fraction
Total	**4,138,159**	**100.00%**
Civil Underground *	2,125,000	51.35%
Civil Above Ground	310,000	7.49%
Arc Magnets	791,767	19.13%
Correctors & Special Magnets	112,234	2.71%
Vacuum	153,623	3.71%
Installation	232,397	5.62%
Tunnel Cryogenics	22,343	0.54%
Refrigerators	94,785	2.29%
Interaction Regions	26,024	0.63%
Other Accelerator Systems	269,986	6.52%

* Underground construction cost is the average of the costs of three orientations, and includes the cost of a AE/CM firm at 17.5% of construction costs.

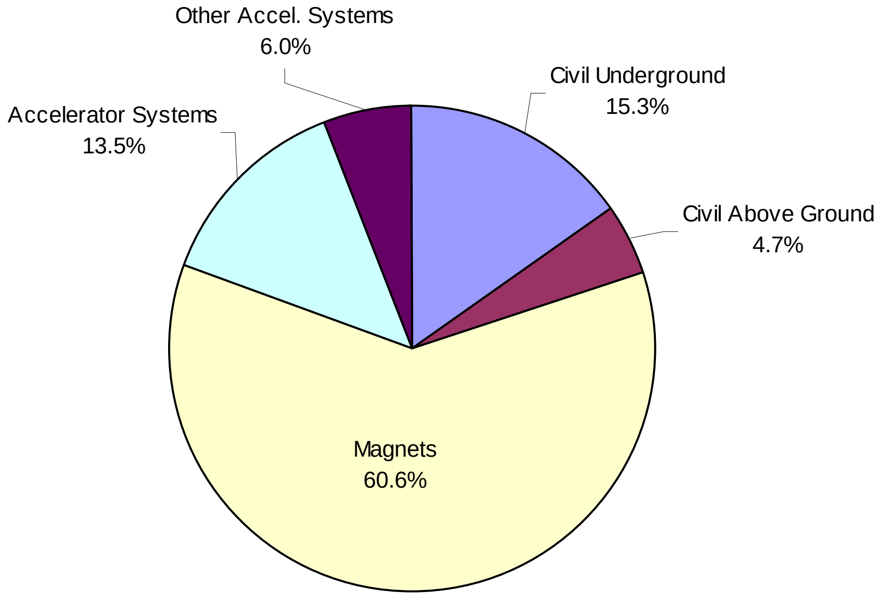
For comparison, the SSC Collider Ring, escalated to 2001 (1.35) is $3.79 billion

The Reality Check - SSC Basis

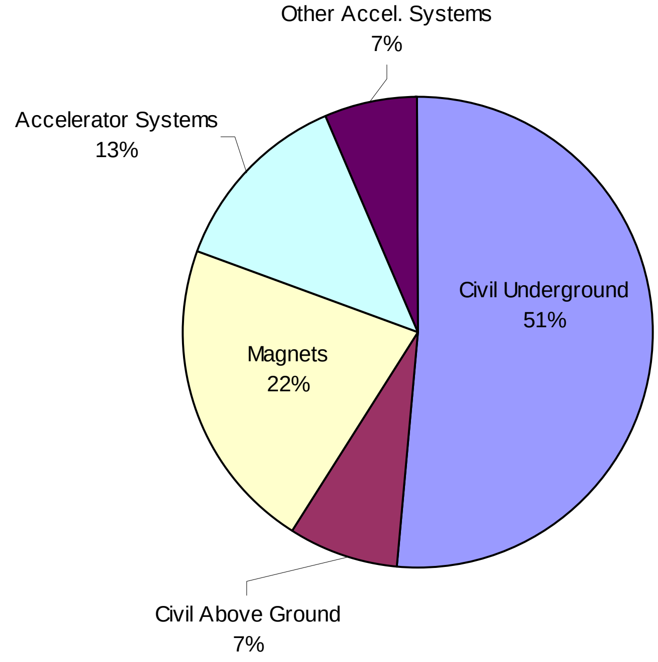
- **Estimated only the SSC Collider Ring and associated items**
  - Injection lines, beam abort, etc. In other words, the same scope as VLHC.
- **Used July, 1990 SSC Cost Estimate – The SCDR Baseline**
  - No adjustments by reviews. The real cost increase was about $200 million. (There were other adjustments to SSC cost not relevant to this analysis.)
- **Used only the "European" cost base**
  - Tried to strip out all EDI, indirects, escalation and contingency – a "European" base estimate, directly comparable to the recent TESLA estimate.
- **Deconstructed the SSC estimate and reconstructed it into the VLHC categories and adjusted to the VLHC design.**
  - Adjusted number of detector halls, for example; moved special magnets from Accelerator Systems to Magnet category
  - Added the "other accelerator systems" to VLHC by the SSC ratio of AccelSys/(Cryo+Vacuum+Install)
- **Escalated SSC from 1990 to 2001 by 35% (CPI)**

Comparison of VLHC and SSC Cost Drivers

SSC Cost Ratios



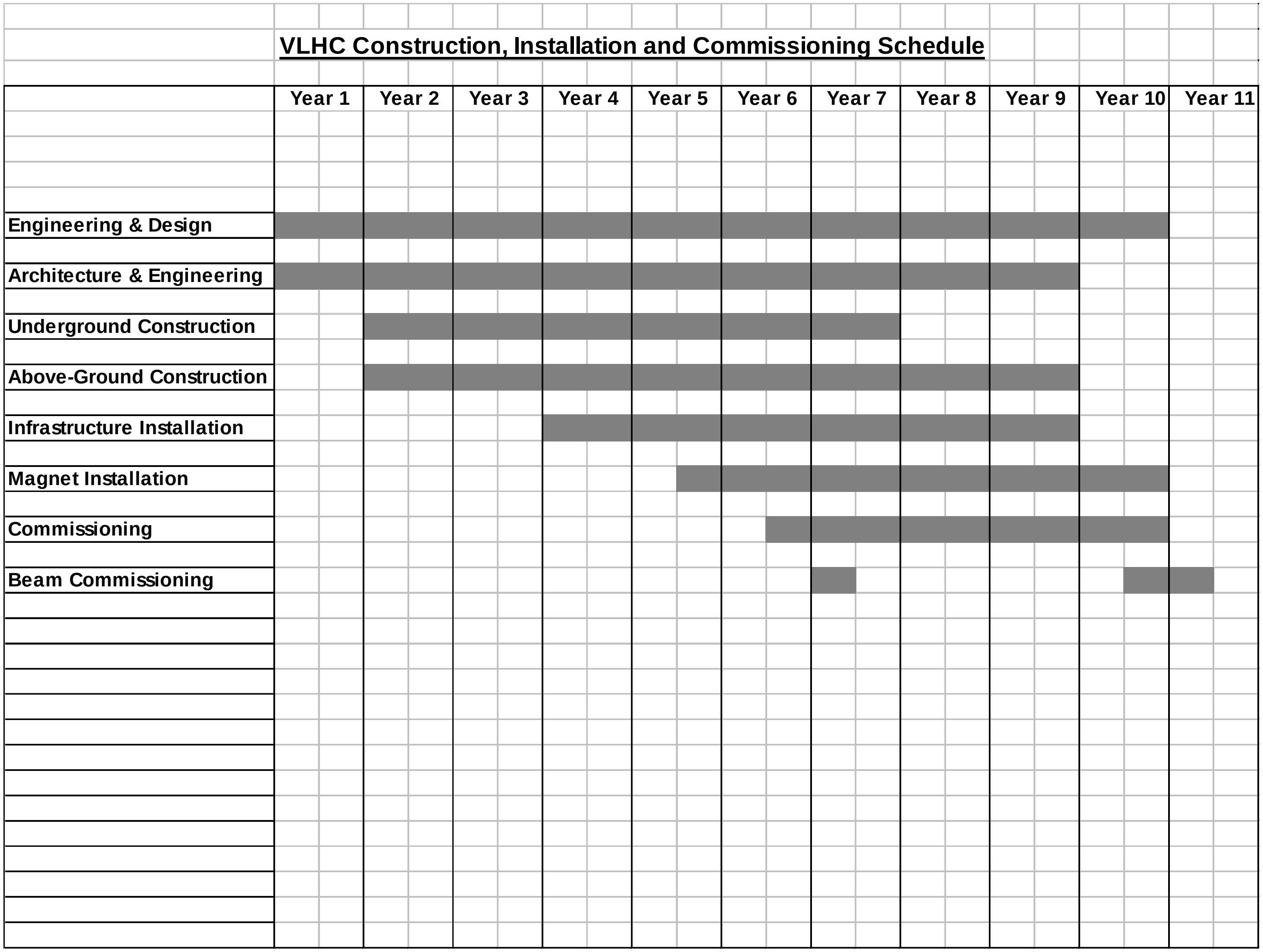
VLHC Cost Ratios



Comparison:

VLHC total cost is estimated to be $4.1 Billion

SSC collider ring cost, escalated to 2001 is estimated to be $3.8 Billion.


VLHC Construction, Installation and Commissioning Schedule
Year 1
Year 2
Year 3
Year 4
Year 5
Year 6
Year 7
Year 8
Year 9
Year 10
Year 11
Engineering & Design
Architecture & Engineering
Underground Construction
Above-Ground Construction
Infrastructure Installation
Magnet Installation
Commissioning
Beam Commissioning

Getting to the Total Cost

- **The factors below apply to any and all cost estimates.**
  - EDI, Engineering, Design and Inspection.
  - Overhead and G&A, or indirects
  - Escalation
  - Contingency
- **Scaling from the TESLA cost estimate, we might estimate EDI + Overhead at 10,000 person-years, ~ $1 billion. This will be split among Fermilab and collaborating institutions.**
  - TESLA estimated 7,000 person-years for an eight-year construction cycle; 4,000 came from DESY - the whole Accelerator Div. (500 people) working full time on it. The rest of the manpower comes from collaborating institutions.
- **In addition, there are two detectors to be estimated.**
- **At this time, the estimate needs adequate contingency. Engineering and R&D will reduce it.**

Stage 1 R&D to Demonstrate Feasibility

- **Magnet field quality at injection and collision energy**
  - Produce field quality model magnets. About six months
- **Beam instabilities and feedback**
  - A combination of calculation, simulation & experiments
- **High-field quadrupoles are required for the IR**
  - Similar to 2nd-generation LHC IR quads – a Fermilab goal for LHC
- **Other R&D will be accomplished in a magnet string test that we intend to have fully operational in 3 to 4 years**
  - **Magnet production and handling**
    - Demonstrate ability to produce and handle long magnets
  - **Cryogenic behavior; possible flow instabilities due to long lines**
    - Heat leak is a critical factor
  - **Demonstrations and designs of other systems.**

Stage 1 R&D to Reduce Costs

- **Tunneling R&D: tunneling is the most expensive single part**
  - Automation to reduce labor component and make it safer
  - Improvements in reliability, utilization and logistical support
  - Careful design & coordination with AP and HEP to reduce special construction
- **Magnet production and handling; long magnets reduce cost**
  - Reduce assembly time, labor & storage; fewer devices to install
- **Vacuum; surprisingly expensive**
  - Develop getters that work for methane, or investigate cryopumps
- **Improvements in many smaller systems**
  - Complete development and designs of many accelerator systems

Further Studies

- It is appropriate to continue the design study
  - Complete a second pass of the Design Study during the next two years
    - Narrow the cost uncertainty
    - Improve the designs of both Stage 1 and Stage 2 VLHC
    - Develop other VLHC possibilities; parametric studies and optimization
    - Study installation and construction scheduling and interleaving
    - Begin the environmental impact studies
    - Start to study some management possibilities
  - Physics studies
    - Begin to understand the opportunities of the VLHC for both stages
    - Study the detector issues of both stages, and outline necessary R&D
  - Public outreach
    - It is not too early to start to approach our neighbors and our governments.
    - We need to encourage international cooperation and participation.

Why a Two-Year Plan for the Next Design Study?

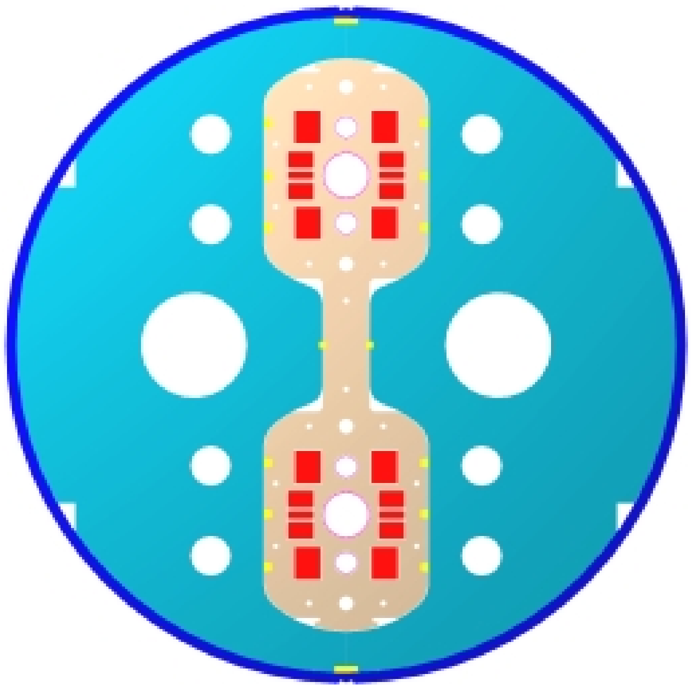
- **To build successful teams for successful studies**
  - To build teams the Labs have to show commitment. Immediate goals do that; stretched-out schedules do not.
  - One year is not long enough for the amount of work; four years is too long.
- **To start an effort that will continue**
  - The Studies are an iterative process. Two years is only the first phase.
  - R&D is a continuous activity that needs AP, engineering and HEP input to be focused and successful.
- **To have a plan consistent with all possible scenarios**
  - If an LEC is built elsewhere, America must have a future as a leader of HEP, even if we are a major collaborator on LEC.
  - If an LEC is not built, we must be able to move to something else quickly. We cannot afford to flounder as we did after the cancellation of the SSC.
  - If LEC construction begins in the U.S., the intensity of VLHC Studies can be decreased at that time.

Stage 2 R&D

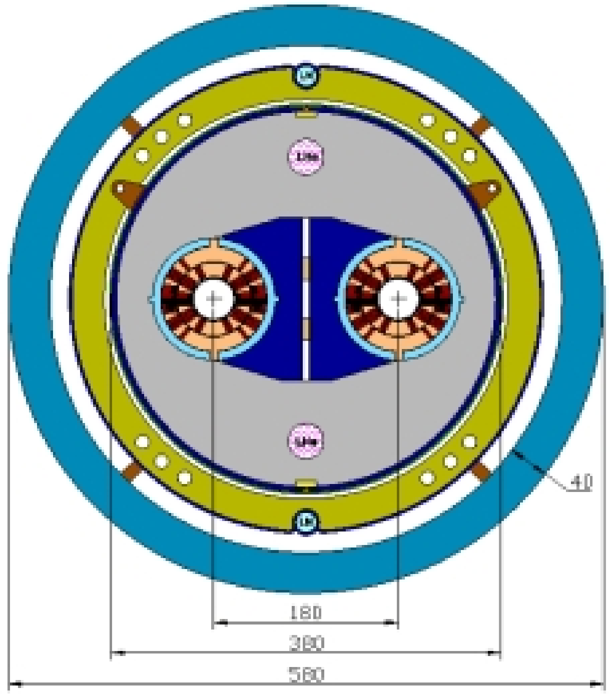
- A longer time scale
  - **Magnet development**
    - High-field magnets are not yet industrial products.
  - **Conductor performance**
    - High-field magnets need high-performance conductor.
  - **Magnet and conductor cost**
    - The conductor cost is mostly market driven.
  - **Synchrotron radiation induced cryogenic and vacuum issues**
    - Must investigate vacuum issues; requires R&D at light sources.
    - SynchRad masks will reduce refrigerator capital & operating costs.
  - **Detector R&D**
    - How to handle many interactions per crossing
    - High debris power in the IP. This is mostly a magnet issue.

Stage 2 R&D - Magnets

❖ There are several magnet options for Stage 2.



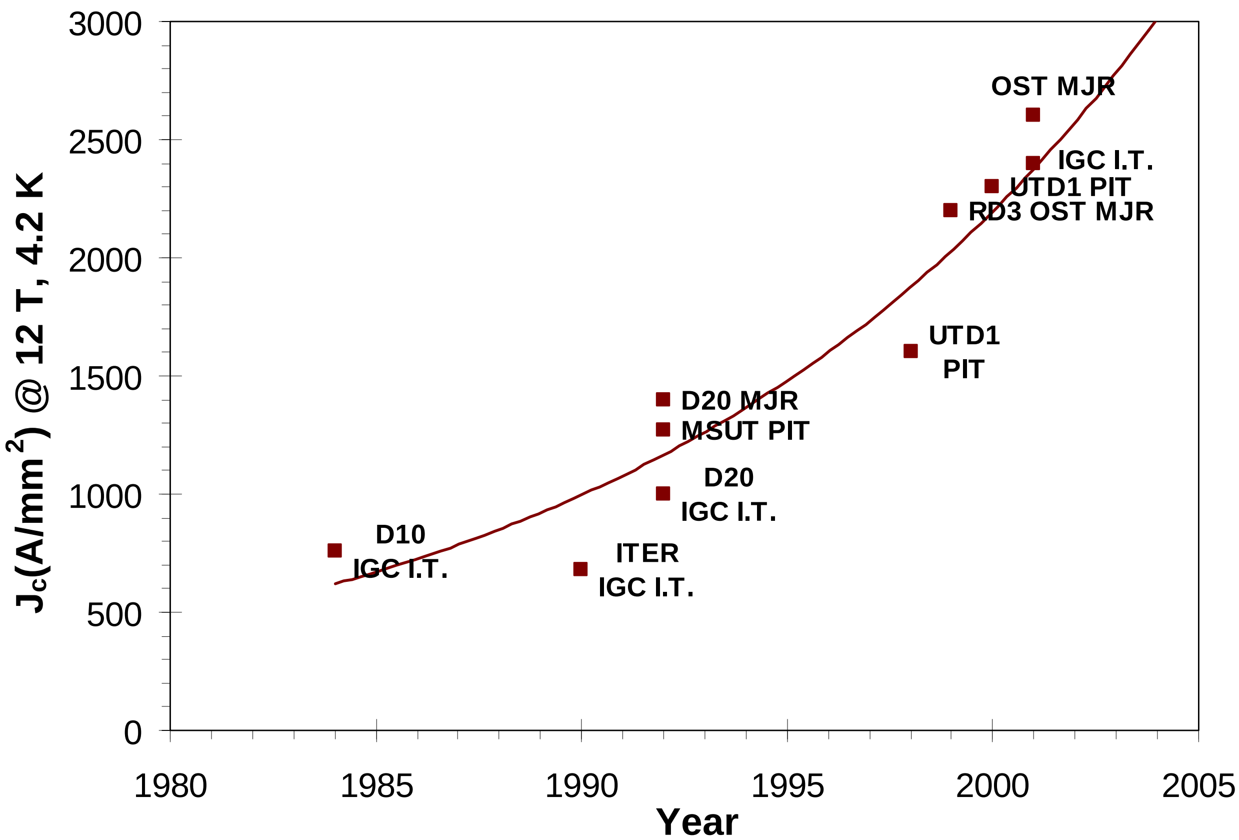
Stage-2 Dipole Single-layer common coil



Stage-2 Dipole Warm-iron Cosine Θ

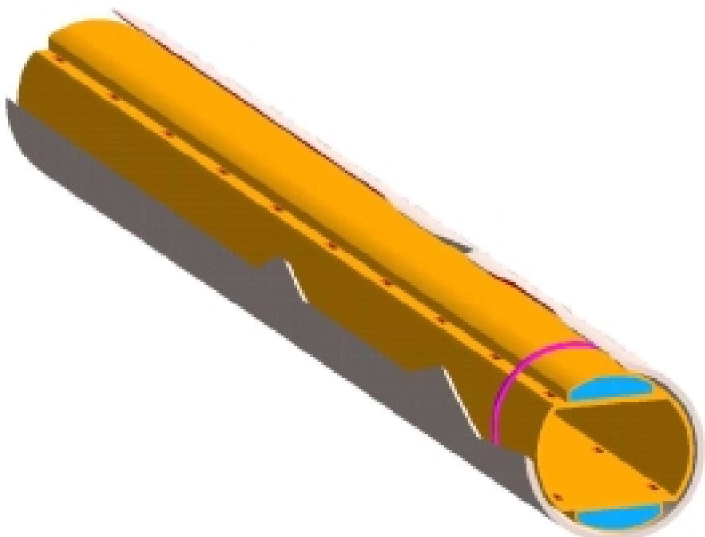
Stage 2 R&D - Conductor

❖ Nb3Sn conductor is continuing to improve

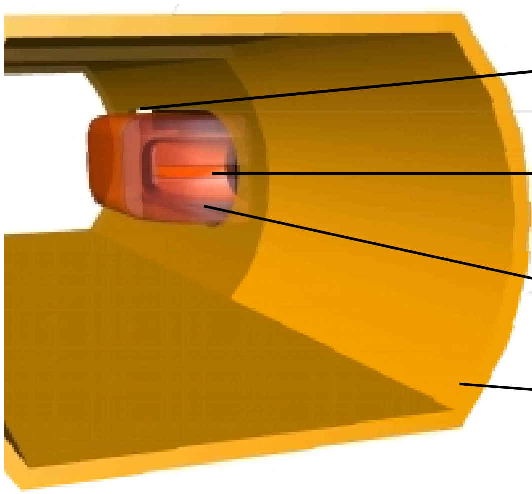


Stage 2 R&D – Vacuum and Cryogenics

❖ Synchrotron radiation masks look promising. They decrease refrigerator power and permit even higher energy

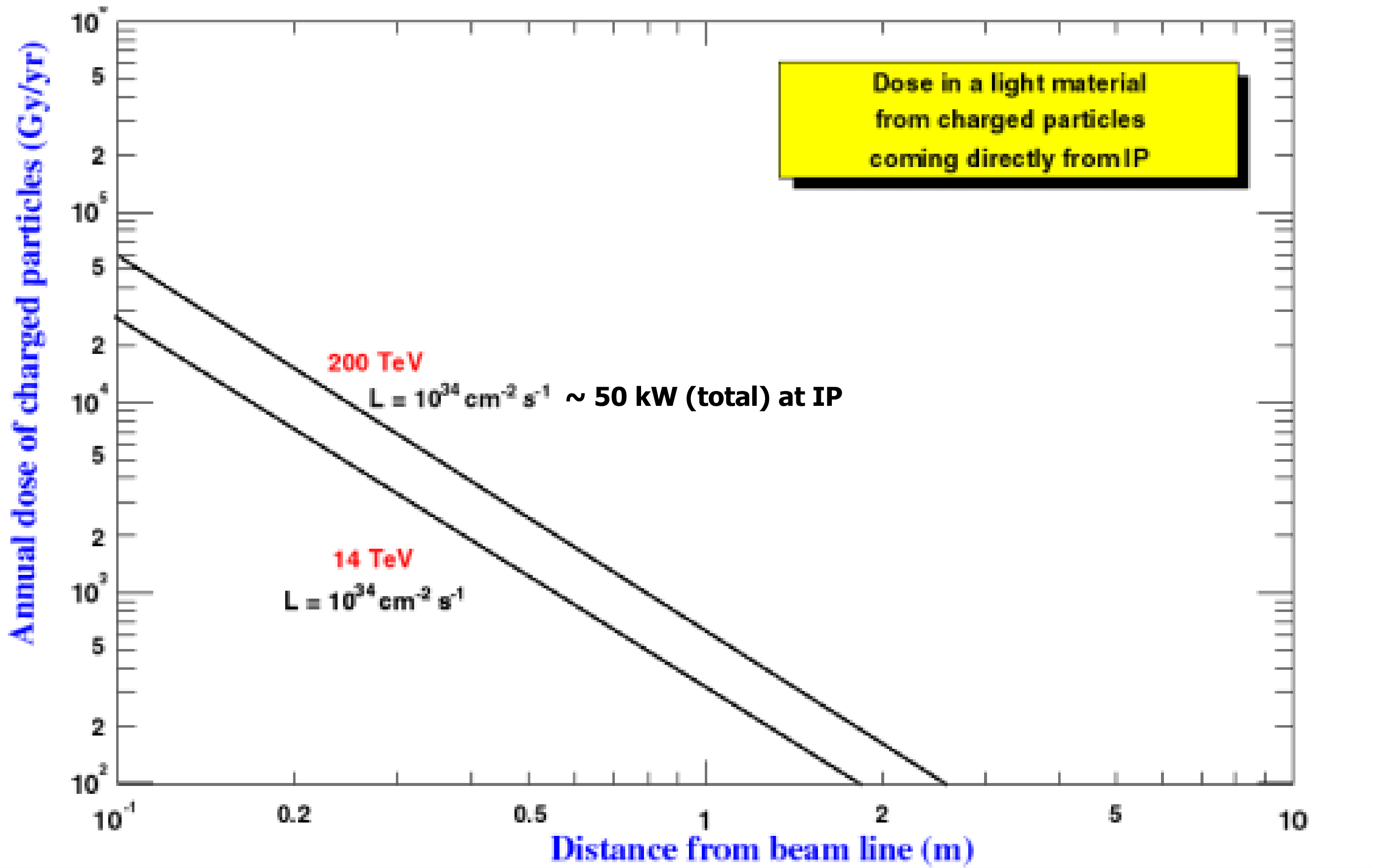


A "standard" beam screen will work up to 200 TeV and 2x10^{34}



A synchrotron radiation "mask" will allow even higher energy and luminosity, and is practical only in a large-circumference tunnel.

Detector Radiation Dose



A Plausible Scenario for the VLHC

Let's assume that an LEC will be built starting fairly soon, but not in the U.S.

- **Given adequate resources, we could propose building a staged VLHC at Fermilab with a construction start in about five years.**
  - However, that may not be the best plan for high-energy physics in the long term, because HEP must have worldwide cooperation to accomplish its goals. Hence, the U.S. should be a significant collaborator in an LEC, no matter where it is built.
  - This might be as much as $1 billion, spread over eight years, with peak spending ~$200 million/year including lab salaries.
- **In the meantime, VLHC R&D, engineering studies and planning must continue, to be ready for the next step.**

A Plausible Scenario for the VLHC

- **When the TESLA spending profile starts to turn down, the US should begin to build the VLHC at Fermilab with collaboration from other regions.**
  - This could be about 2008/2009 according to the fastest TESLA plan
- **Another region might do improved neutrino physics**
  - This might involve a muon storage ring if R&D is successful, or it could involve a high-power proton source.
- **R&D for a third-generation lepton collider, CLIC-like, or a muon collider should continue.**
- **With a truly international plan, there will be resources for underground labs, particle astrophysics and other experiments and facilities.**

A Plausible Scenario for the VLHC

- **Details:**
  - 2004: U.S. funding starts to increase, eventually reaching 25% higher (than it is now) to help build an LEC elsewhere.
    - About $75 million/year (at peak) comes out of the "base program" to fund the salaries working on an LEC and its experiments.
  - 2009: LEC construction funding starts to decrease. U.S. begins construction of the VLHC. The U.S. funding level begins another increase, eventually reaching an additional 50% to fund VLHC.
  - 2013: TESLA Operational!
  - 2020: VLHC Operational!
    - Total VLHC cost (U.S. accounting) about $7 - $8 billion. The U.S. investment is ~ $5 - $6 billion, including about $1 billion out of the U.S. base program for salaries, spread over 10 years, with a peak of $200 million/yr.

Another Scenario for the VLHC

- **A linear electron collider is built in the U.S.**
  - The U.S. investment in a LEC is much higher than if it is built elsewhere.
  - This pushes the start of construction of a VLHC in the U.S. later by many years, perhaps as late as 2020.
  - It's very likely that the world will choose not to wait that long for a push to a new energy scale. The VLHC will be built elsewhere.

- **Reaching a new energy scale is significantly delayed, and it will not happen in the U.S.**

What are we asking from the Subpanel?

- To include the VLHC as part of your plan for high-energy physics.
- To recognize that a staged VLHC is feasible and affordable, and could be the best choice for the next major accelerator facility in the U.S.
- To endorse committing additional resources to increase the R&D for VLHC.
  - The present Stage 1 program is ~ $1 million/year, including salaries. That should increase to ~$2 million/year in FY2002, more in the out years.
  - The goal is a fully operational string test with long magnets, and a robust tunneling R&D effort in 3 to 4 years.

What are we asking from the Subpanel?

- **To support continuing the engineering and design effort.**
  - The goal is to produce a refined second design report in about two years, including smaller cost uncertainty, environmental studies, parametric studies yielding an optimized design, and possible management schemes. We estimate 10 – 15 FTEs, including some tunneling experts.
- **To recommend the start of an international effort to study the physics and detectors of both stages of the VLHC.**
  - With a goal of producing a report in about two years.
- **To recommend extension of an analogue of the Subpanel process, or some type of high-level commission to begin serious international planning for high-energy physics.**
  - This must happen! The instruments of HEP are too costly and take too long to build to fall to individual regions.

Conclusions

- We have completed a first study of a staged VLHC. The study shows that:
  - The VLHC is both feasible and affordable, with a cost comparable to that of a linear collider.
  - The first stage can reach 40 TeV and 1×10^{34}; the second stage can reach 200 TeV and at least 2×10^{34}.
  - There are no major technical obstacles to realizing the desired performance goals of the Stage 1 VLHC.
  - Only a modest amount of R&D is needed to prove the design and narrow the cost estimate. This work can be accomplished in five years.
- The staged VLHC should be part of the roadmap recommended by this Subpanel.
- The staged VLHC should be the next major accelerator initiative in the U.S.