Cost Conclusions of the Study

- The cost driver is underground construction, especially tunneling. A vigorous R&D and engineering program directed at tunneling can reduce the cost and the cost uncertainty.
- The total cost for Stage 1 appears to be slightly higher, 10% to 30%, than the cost for TESLA (~ $3 billion, as recently estimated by DESY).
- The cost for the Stage 1 collider is consistent with the cost for the SSC Collider Ring inflated to 2001 dollars.
- It's necessary to build the VLHC at an existing hadron accelerator lab.
- There are obvious cost drivers, and obvious places to concentrate cost-reducing R&D.

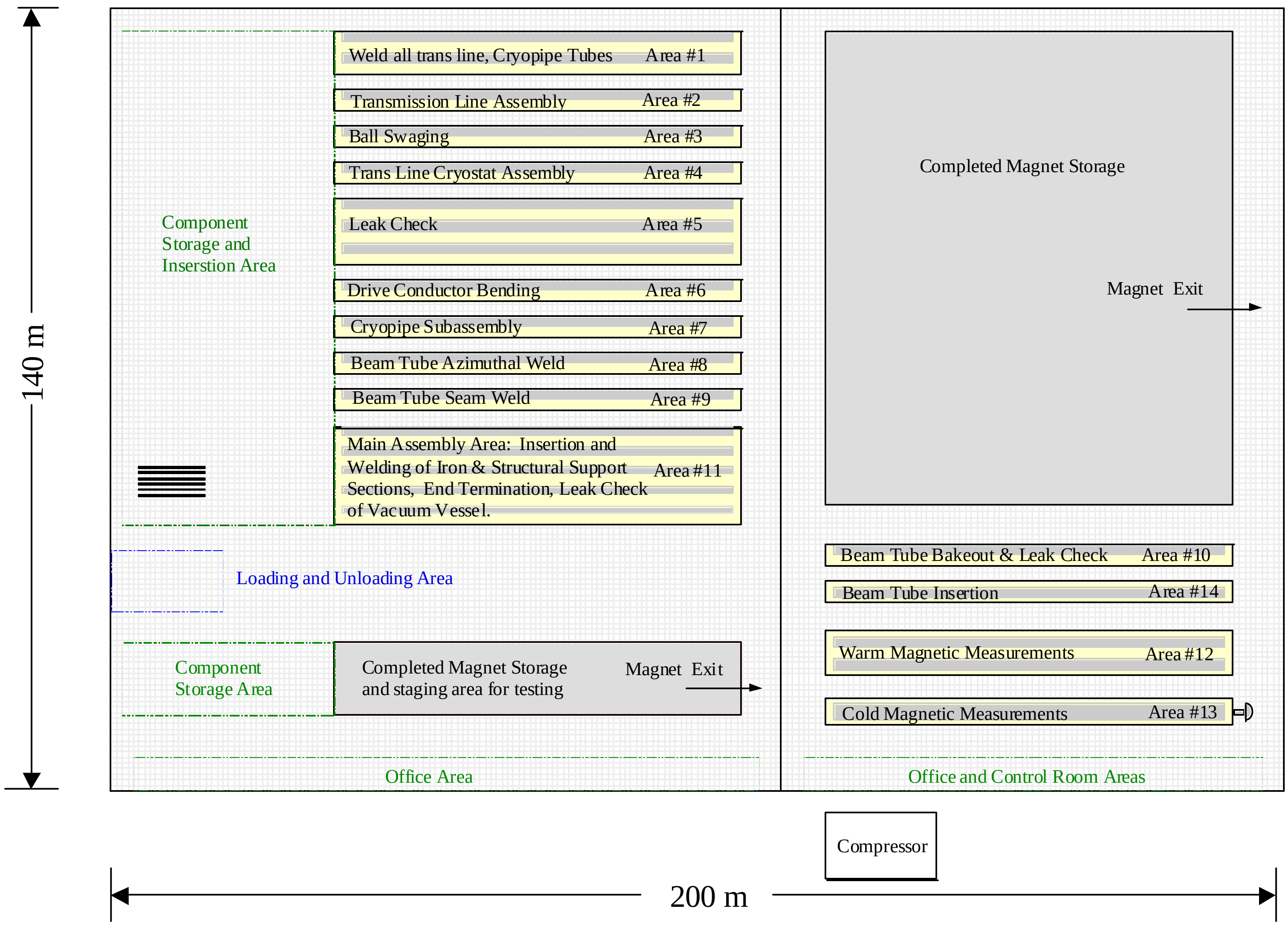
Preliminary Review

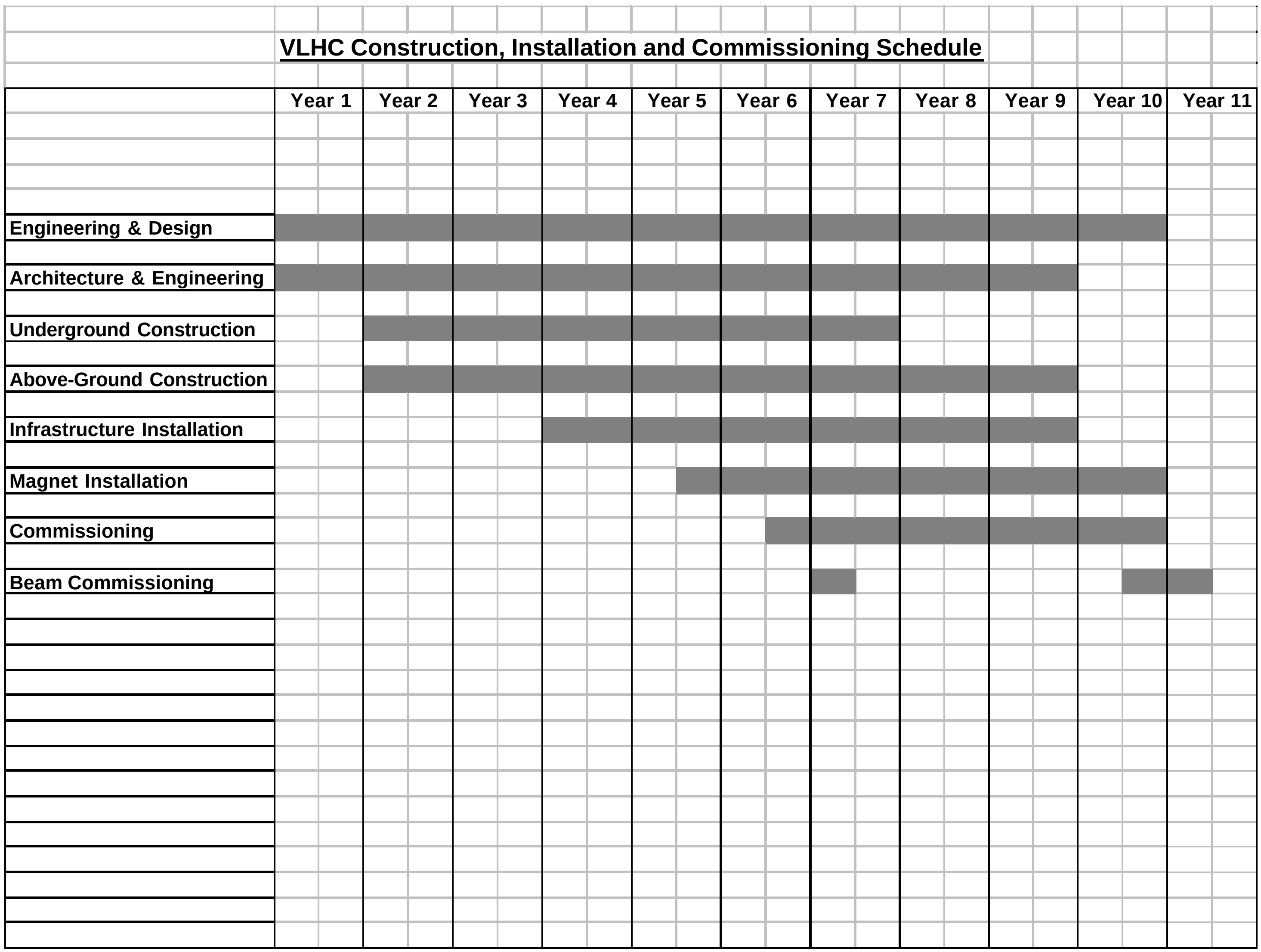
- A preliminary review was held April 30, May 1, 2001, as a check to see if we were way off base before releasing our report.
  - **Review Committee:**
    - Bob Kephart, Fermilab, Chairman
    - Gerry Dugan, Cornell; Jon Ives, consultant; Eberhard Keil, CERN
    - Philippe Lebrun, CERN; Al Zeller, MSU; 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."**

VLHC 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 what we thought would be the cost drivers using a standard cost-estimating sheet. This is done at a fairly high level.**
  - Underground construction
  - Above-ground construction
  - 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.**

Very Large Hadron Collider




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

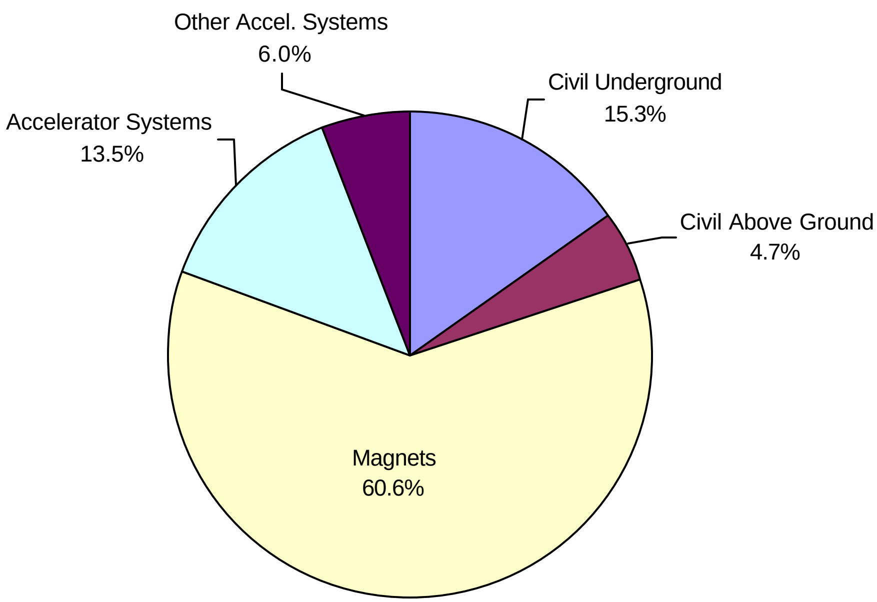
SSC Basis

- **Used July, 1990 SSC Cost Estimate – The SCDR Baseline**
  - No adjustments by reviews. The real cost increase was about $200 million; this adjustment remains to be done. (There were other adjustments 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.
- **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 AccelSys 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)**

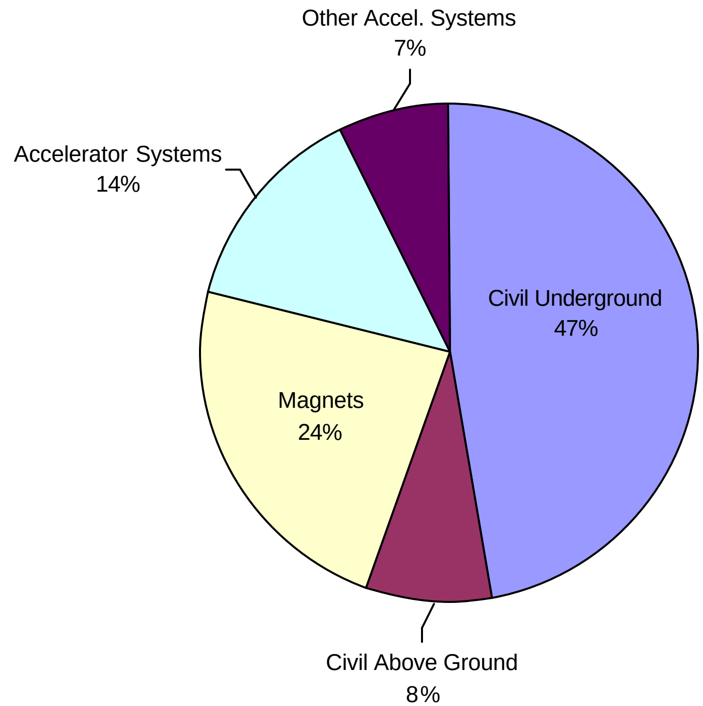
Comparison of VLHC and SSC Cost Drivers

	SSC	VLHC
	100.00%	100.00%
Civil Underground	15.29%	47.33%
Civil Above Ground	4.66%	7.89%
Magnets	60.59%	23.77%
Accelerator Systems	13.50%	13.91%
Other Accel. Systems	5.96%	7.10%

SSC Cost Ratios



VLHC Cost Ratios



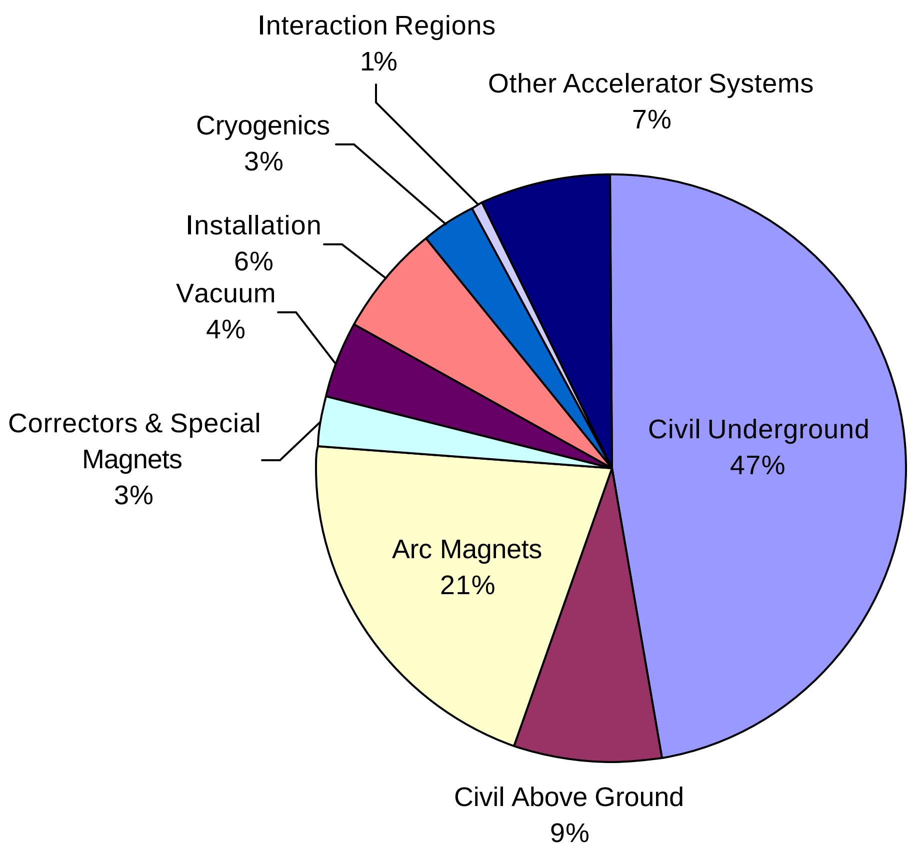
Very Large Hadron Collider

VLHC Cost Drivers

In FY2001 K$	VLHC Estimate	VLHC Fraction
Total	**3,803,159**	**100.00%**
Civil Underground	1,800,000	47.33%
Civil Above Ground	300,000	7.89%
Arc Magnets	791,767	20.82%
Correctors & Special Magnets	112,234	2.95%
Vacuum	153,623	4.04%
Installation	232,397	6.11%
Tunnel Cryogenics	22,343	0.59%
Refrigerators	94,785	2.49%
Interaction Regions	26,024	0.68%
Other Accelerator Systems	269,986	7.10%

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

VLHC Ratios


Interaction Regions
1%
Other Accelerator Systems
7%
Cryogenics
3%
Installation
6%
Vacuum
4%
Correctors & Special
Magnets
3%
Civil Underground
47%
Arc Magnets
21%
Civil Above Ground
9%

What's 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, based on the whole Accelerator Div. (500 people) working full time on it. The rest of the manpower came from collaborating institutions.
- In addition, there are two detectors to be costed.
- At this time, contingency needs to be high. Engineering and R&D will reduce it.

Stage 1 R&D

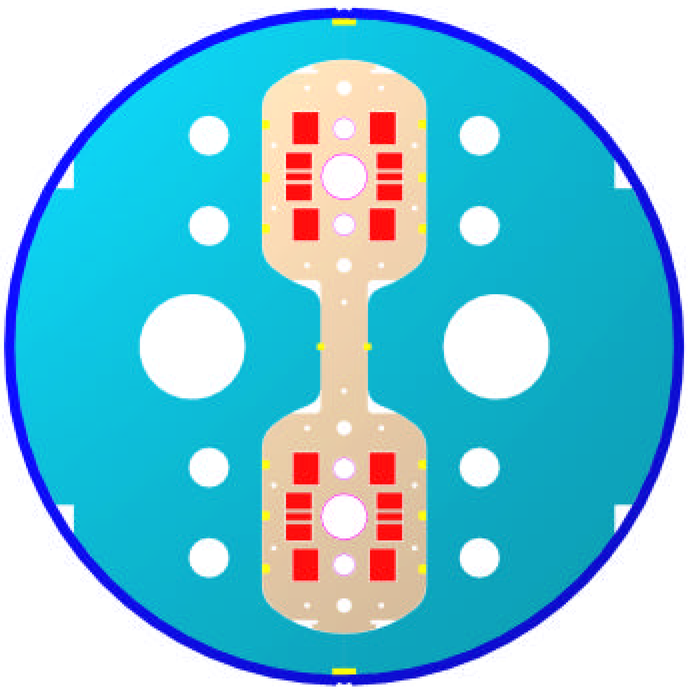
- The purpose of R&D is to reduce technical risk and cost, and to improve performance.
  - Tunneling R&D: tunneling is the most expensive single part
    - Automation to reduce labor component and make it safer
    - Careful design & coordination with AP and HEP to reduce special construction
  - Beam instabilities and feedback: the largest risk factor
    - A combination of calculation, simulation & experiments
  - Magnet field quality at injection and collision energy
    - This does not appear to be an issue, but needs more study
  - Magnet production and handling; long magnets reduce cost
    - Reduce assembly time, labor & storage; fewer devices to install
  - High-field quadrupoles are required for the IR
    - Similar to 2nd-generation LHC IR quadrupoles
  - Installation; a complicated, interleaved procedure to save time
    - Handling long magnets is tricky
  - Vacuum; surprisingly expensive
    - Develop getters that work for methane, or cryopumps
  - Cryogenic behavior; possible instabilities due to long lines
    - Heat leak is a critical factor

Stage 2 R&D

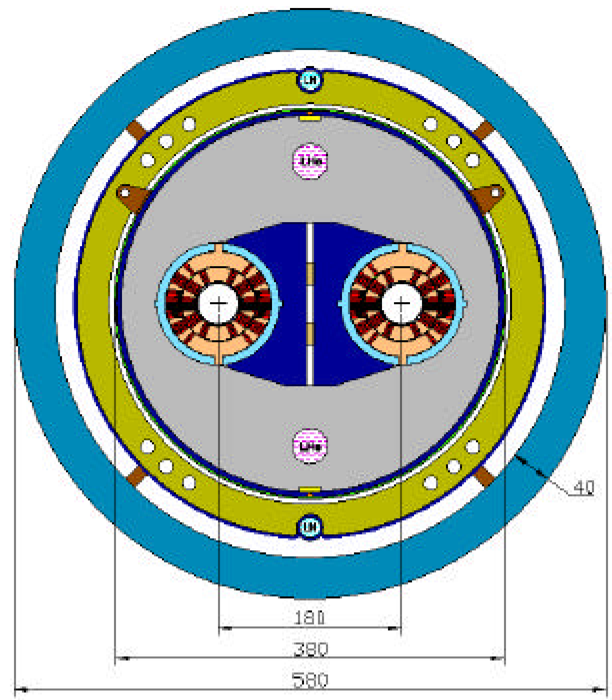
- The purpose of R&D is to reduce technical risk and cost, and to improve performance.
  - Magnet development
    - High-field magnets are not yet industrial or commercial products.
  - Conductor performance
    - High-field magnets need high-performance conductor.
  - Magnet and conductor cost
    - 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.

Stage 2 R&D - Magnets

- There are several magnet options for Stage 2.



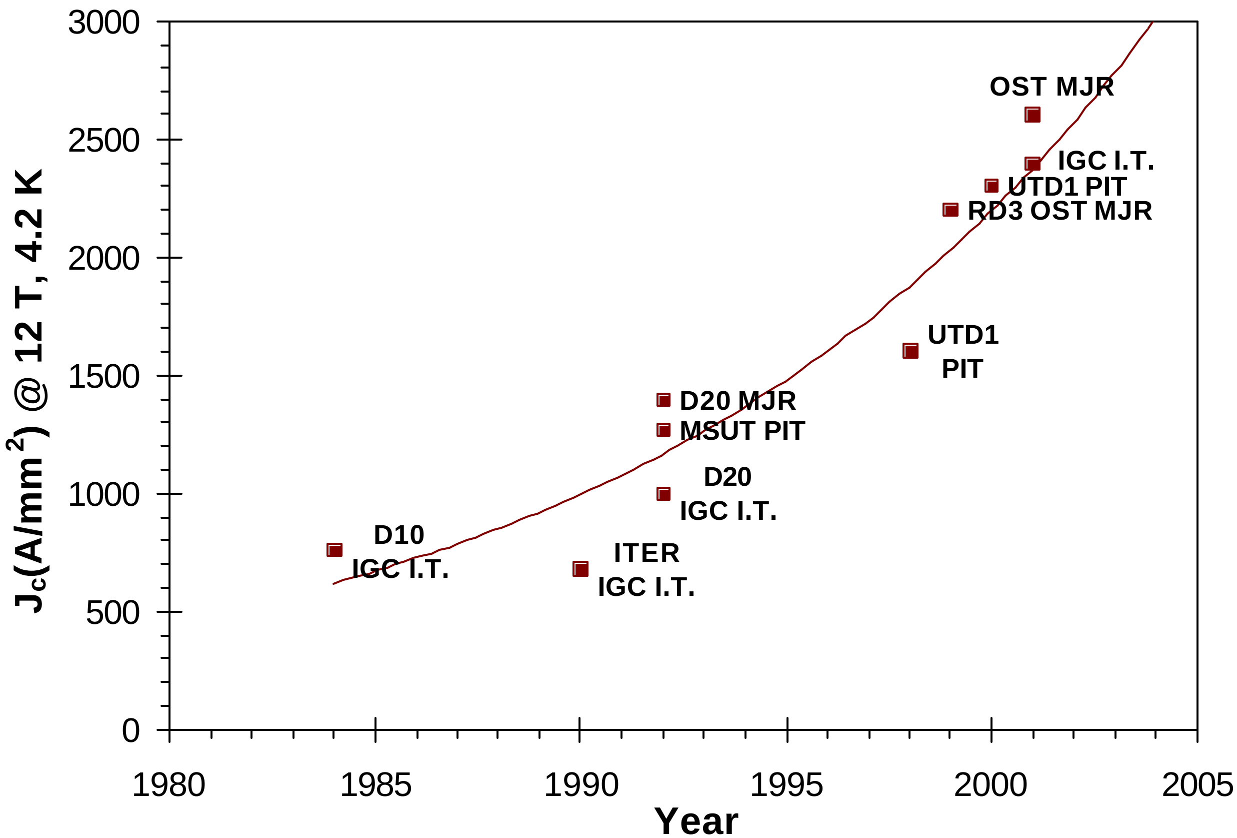
Stage-2 Dipole Single-layer common coil



Stage-2 Dipole Warm-iron Cosine ?

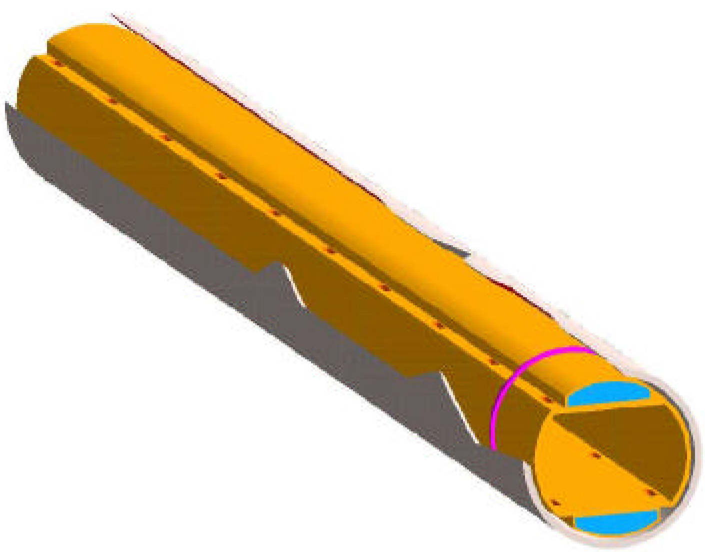
Stage 2 R&D - Conductor

- Nb_3Sn conductor is continuing to improve

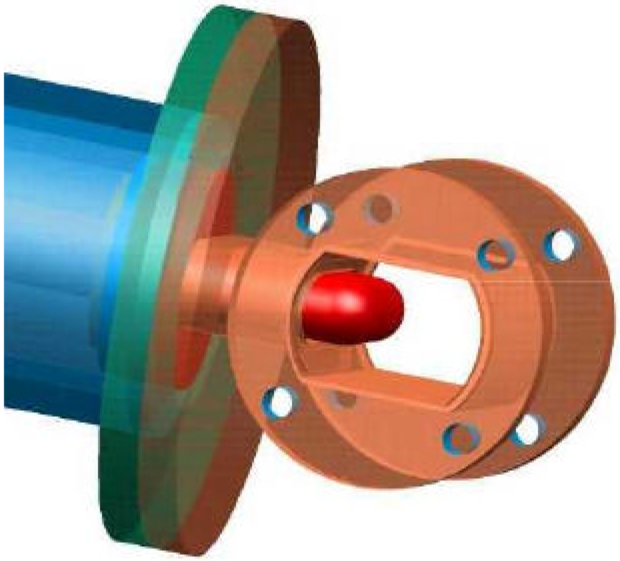


Stage 2 R&D – Vacuum and Cryogenics

- 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

What should HEP, especially Fermilab, do now?

- The purpose of R&D is to reduce technical risk and cost, and to improve performance.
  - Fermilab and others should commit sufficient resources to modestly increase the magnet and accelerator physics R&D for VLHC, to start a serious tunneling R&D effort, and to begin to deal with the length and other systems issues of the Stage 1 magnets.
- In order to understand the engineering, physics and cost issues of the VLHC, we need to assemble an international team to complete an HEP and engineering design.
  - Fermilab and others should commit sufficient resources and provide encouragement to form a complete physics and engineering design team to study the HEP opportunities, to understand the accelerator physics issues, to narrow the cost uncertainties, and to complete an engineering design in two years.

What should world HEP do now?

- Both of the above should be international efforts that require international guidance and management.
  - VLHC needs the imprimatur of the Lab Directors to form an international team to guide VLHC R&D, studies and engineering, with the goal of publishing a complete design and cost estimate in two years.

- The Lab Directors (ICFA?), or even better, the Lab Directors and government science leaders, should start to formulate a worldwide agreement and plan for high-energy physics.
  - This is different from Albrecht Wagner's goal, in that the purpose is not merely to support the next machine, but to make a long-range plan. This is consistent with the charge to Snowmass and the HEPAP Subpanel.

Why a Two-Year Plan?

- **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 scenarios**
  - If an LEC is built in the U.S., the intensity of VLHC Studies can be decreased.
  - If an LEC is built elsewhere, we must perceive a future for our field in America, even if the U.S. is 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.

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.