Outline

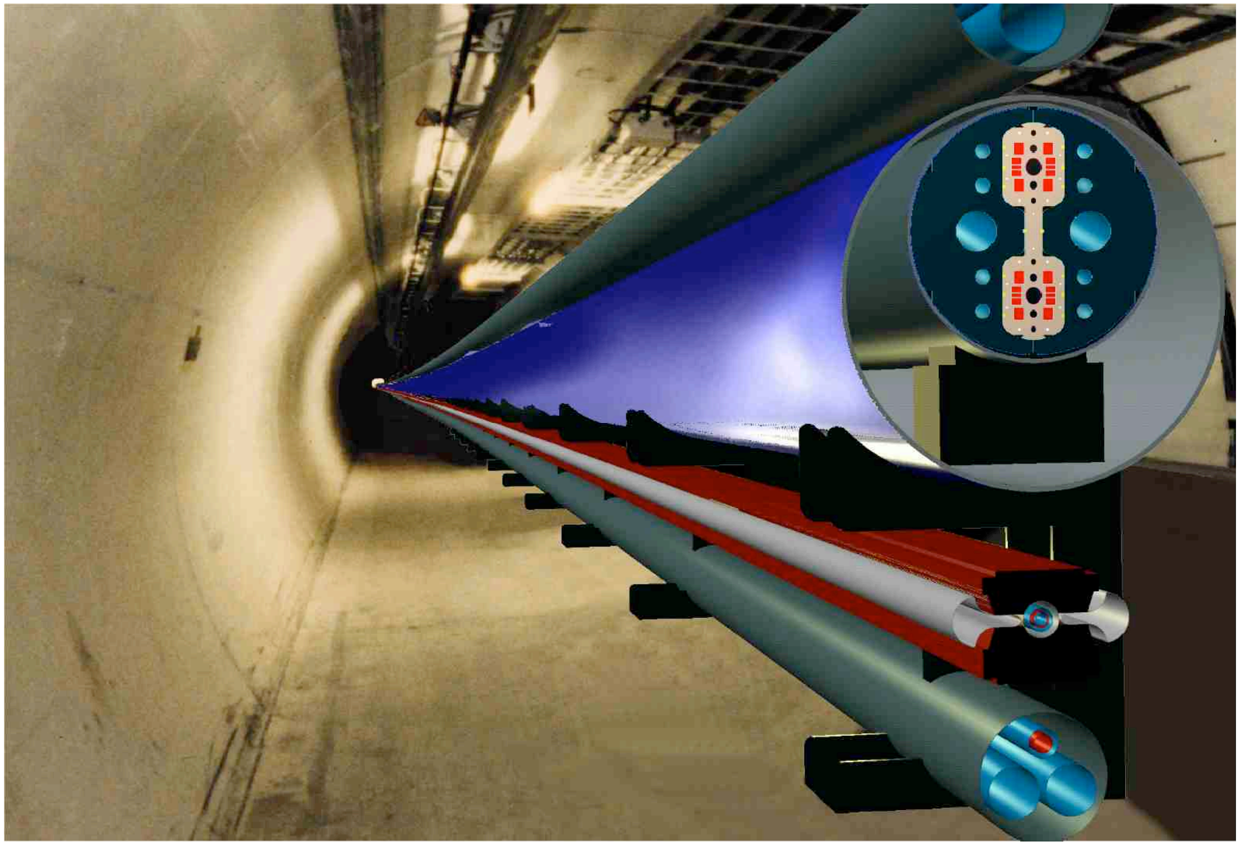
- **A quick review of the VLHC**
  - o A short description
  - o Some important technical points
- **What are the limitations on performance due to synchrotron radiation?**
- **Improving the performance?**

Very Large Hadron Collider

Fermilab-TM-2149
June 11, 2001

www.vlhc.org

Design Study for a Staged Very Large Hadron Collider



The Staged VLHC Concept

- **Take advantage of the space and excellent geology near Fermilab.**
  - **Build a BIG tunnel.**
  - **Fill it with a “cheap” 40 TeV collider.**
  - **Later, upgrade to a 200 TeV collider in the same tunnel.**
    - Spreads the cost
    - Produces exciting energy-frontier physics sooner & cheaper
    - Allows time to develop cost-reducing technologies for Stage 2
    - Creates a high-energy full-circumference injector for Stage 2
    - A large-circumference tunnel is necessary for a synchrotron radiation-dominated collider.
    - This is a time-tested formula for success

Main Ring → Tevatron   LEP → LHC

Conclusions (1)

- **A staged VLHC starting with 40 TeV and upgrading to 200 TeV in the same tunnel is, technically, completely feasible.**

- **There are no serious technical obstacles to the Stage-1 VLHC at 40 TeV and 10^{34} luminosity.**
  - The existing Fermilab accelerator complex is an adequate injector for the Stage-1 VLHC, but lower emittance would be better. (We should take this into account if Fermilab builds a high-power injector. Low emittance is important!)
  - VLHC operating cost is moderate, using only 20 MW of refrigeration power, comparable to the Tevatron.
  - Improvements and cost savings can be gained through a vigorous R&D program in magnets and underground construction.

Conclusions (2)

- **The construction cost of the first stage of a VLHC is comparable to that of a linear electron collider, ~ $4 billion using "European" accounting.**
  - From this and previous studies, we note that the cost of a collider of energy near 40 TeV is almost independent of magnetic field.
  - A total construction time of 10 years for Stage-1 is feasible, but the logistics will be complex.
  - Making a large tunnel is possible in the Fermilab area. Managing such a large construction project will be a challenge.
  - Building the VLHC at an existing hadron accelerator lab saves significant money and time.

Conclusions (3)

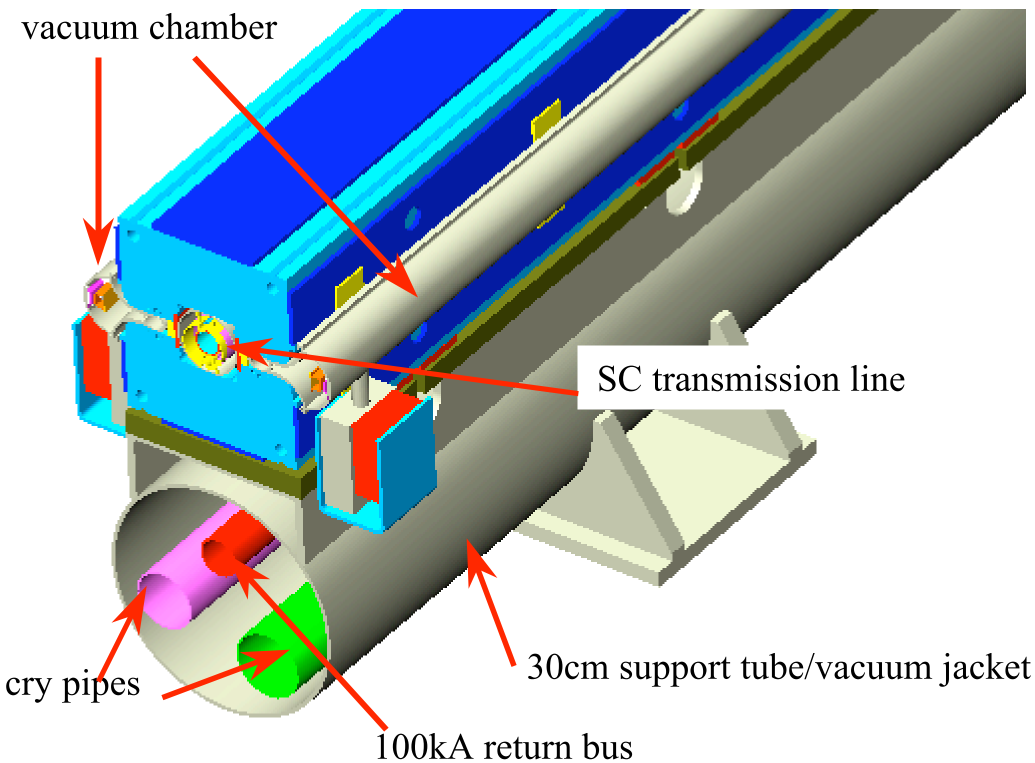
- **The Stage 2 VLHC can reach 200 TeV and $2x10^{34}$ or possibly significantly more in the 233 km tunnel.**
  - A large-circumference ring is a great advantage for the high-energy Stage-2 collider. A small-circumference high-energy VLHC may not be realistic.
  - There is the need for magnet and vacuum R&D to demonstrate feasibility and to reduce cost.
- **Result of work completed after the "Study."**
  - For very high energy colliders, very high magnetic fields (B>12T) are not the best solution.

Very Large Hadron Collider

VLHC Parameters

	Stage 1	Stage 2
Total Circumference (km)	233	233
Center-of-Mass Energy (TeV)	40	200
Number of interaction regions	2	2
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.0×10^{34}
Dipole field at collision energy (T)	2	11.2
Average arc bend radius (km)	35.0	35.0
Initial Number of Protons per Bunch	2.6×10^{10}	5.4×10^{9}
Bunch Spacing (ns)	18.8	18.8
β^* at collision (m)	0.3	0.5
Free space in the interaction region (m)	± 20	± 30
Interactions per bunch crossing at L_{peak}	21	55
Debris power per IR (kW)	6	94
Synchrotron radiation power (W/m/beam)	0.03	5.7
Average power use (MW) for collider ring	25	100

Transmission Line Magnet

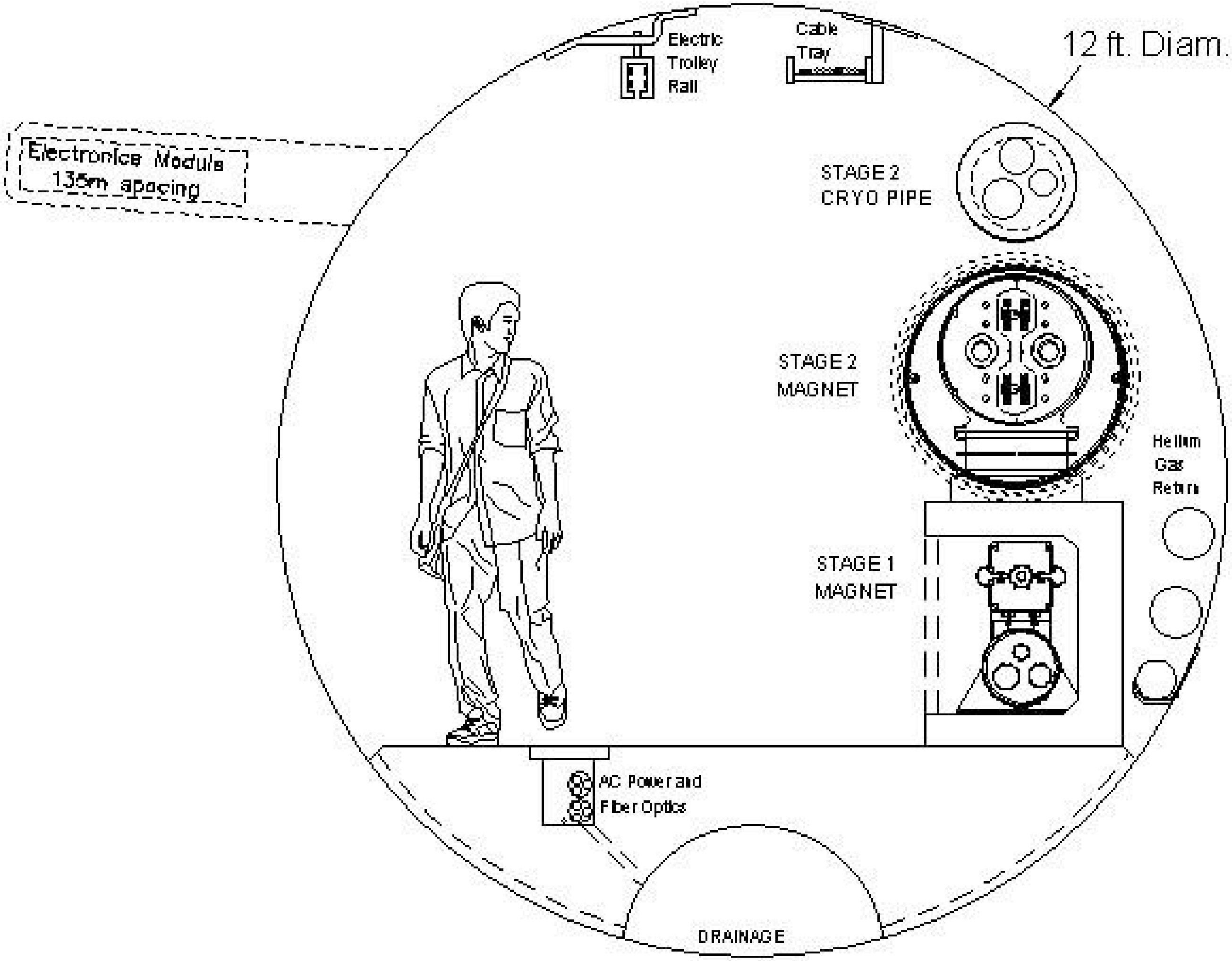


- 2-in-1 warm iron
- Superferric: 2T bend field
- 100kA Transmission Line
- alternating gradient (no quadrupoles needed)
- 65m Length
- Self-contained including Cryogenic System and Electronics Cabling
- Warm Vacuum System

Very Large Hadron Collider

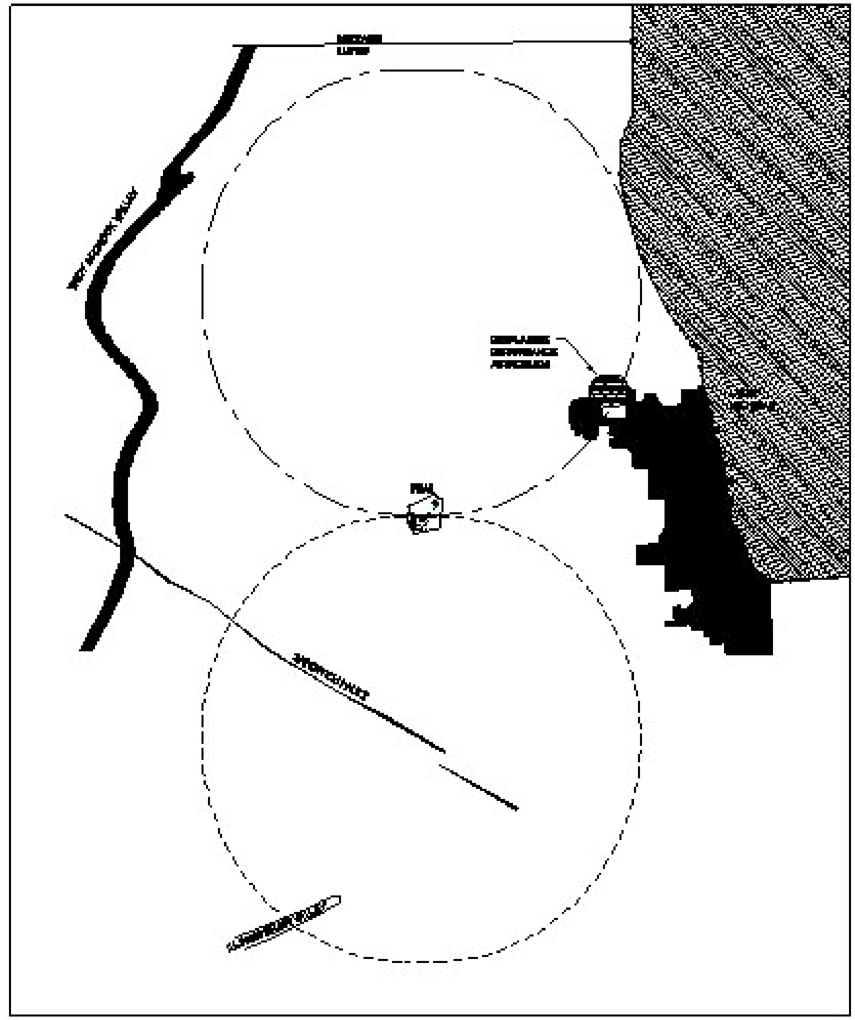
The First Stage-1 Magnet Yokes

VLHC Tunnel Cross Section



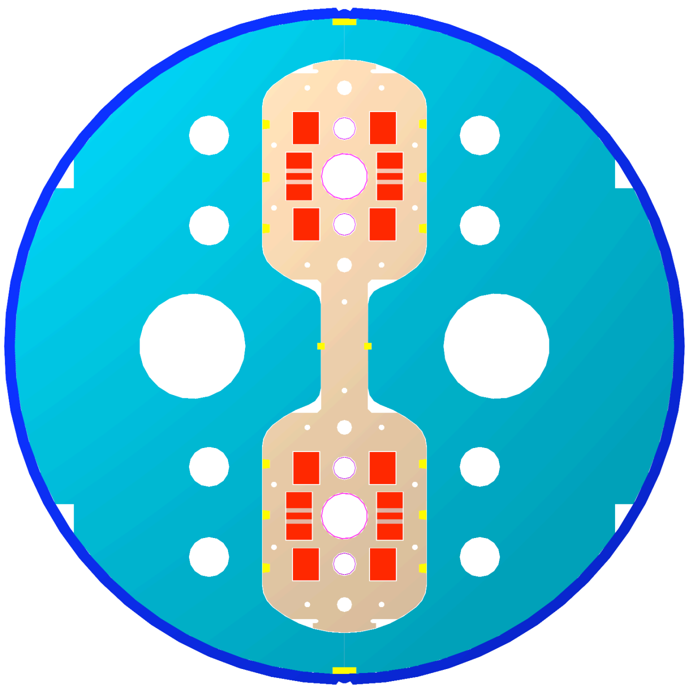
Underground Construction

- **Three orientations chosen to get representative geological samples of sites near Fermilab.**
  - South site samples many geologic strata and the Sandwich fault.
  - One north site is flat and goes through many strata.
  - Other north site is tipped to stay entirely within the Galena-Platteville dolomite, and is very deep.
- **These are not selected sites – merely representative.**
  - Cost of other sites can be built from data gained in these sites.

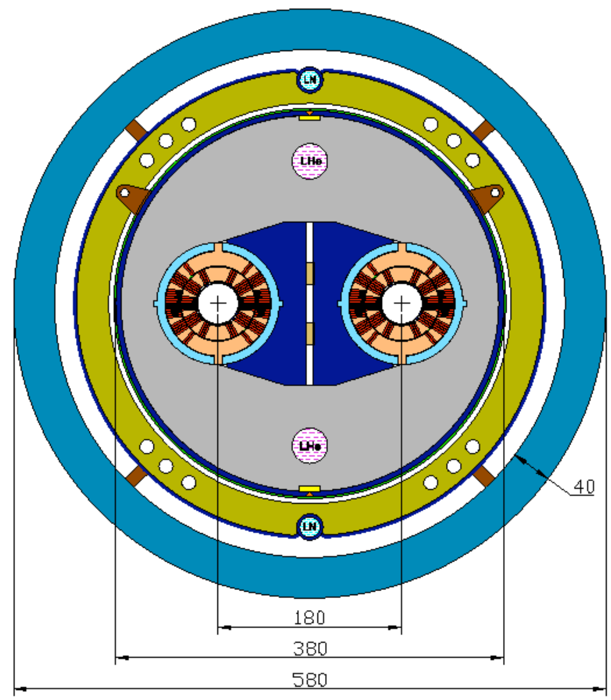


Stage-2 Magnets

❖ There are several magnet options for Stage 2. Presently Nb_3Sn is the most promising superconducting material.



Stage-2 Dipole Single-layer common coil

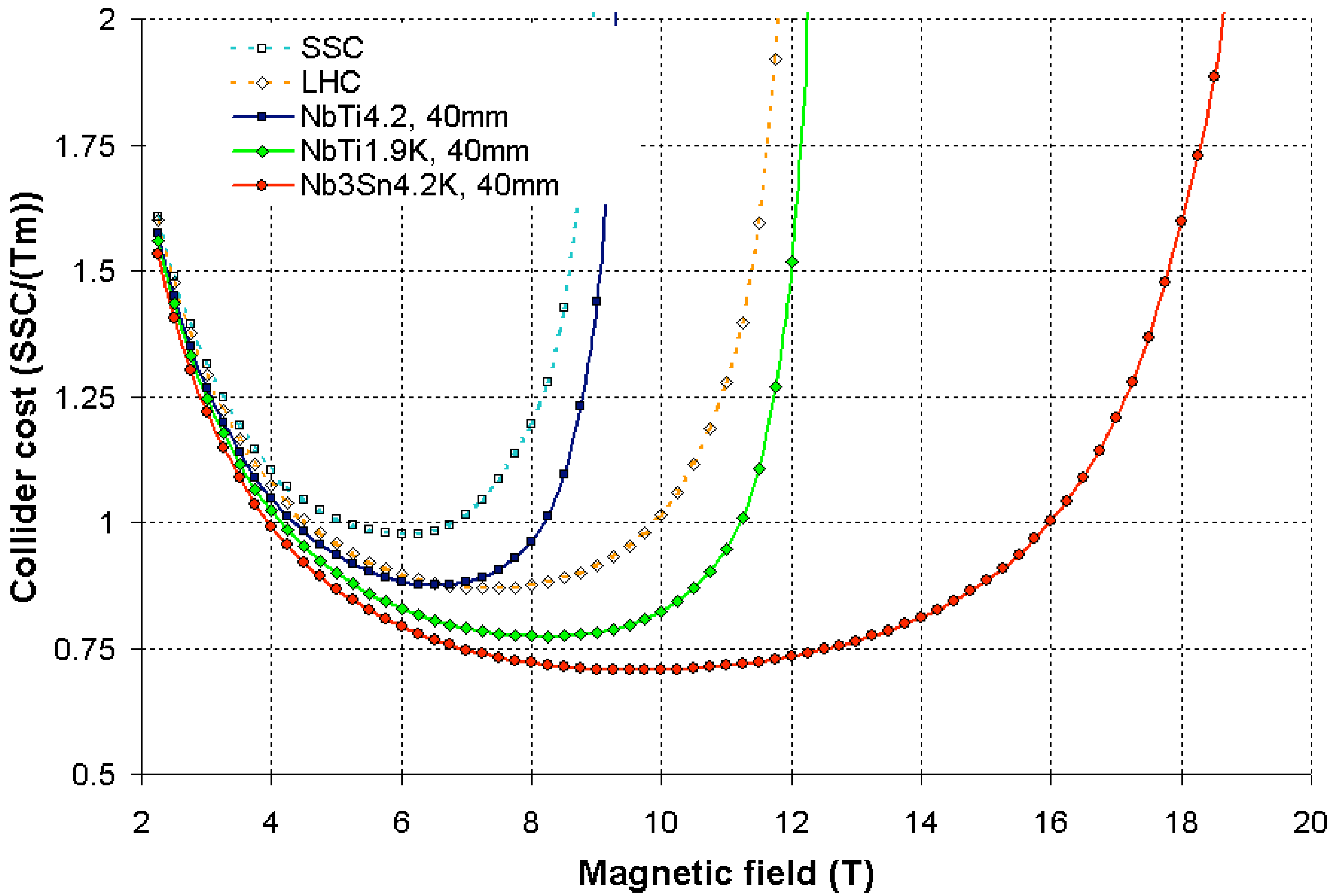


Stage-2 Dipole Warm-iron Cosine θ

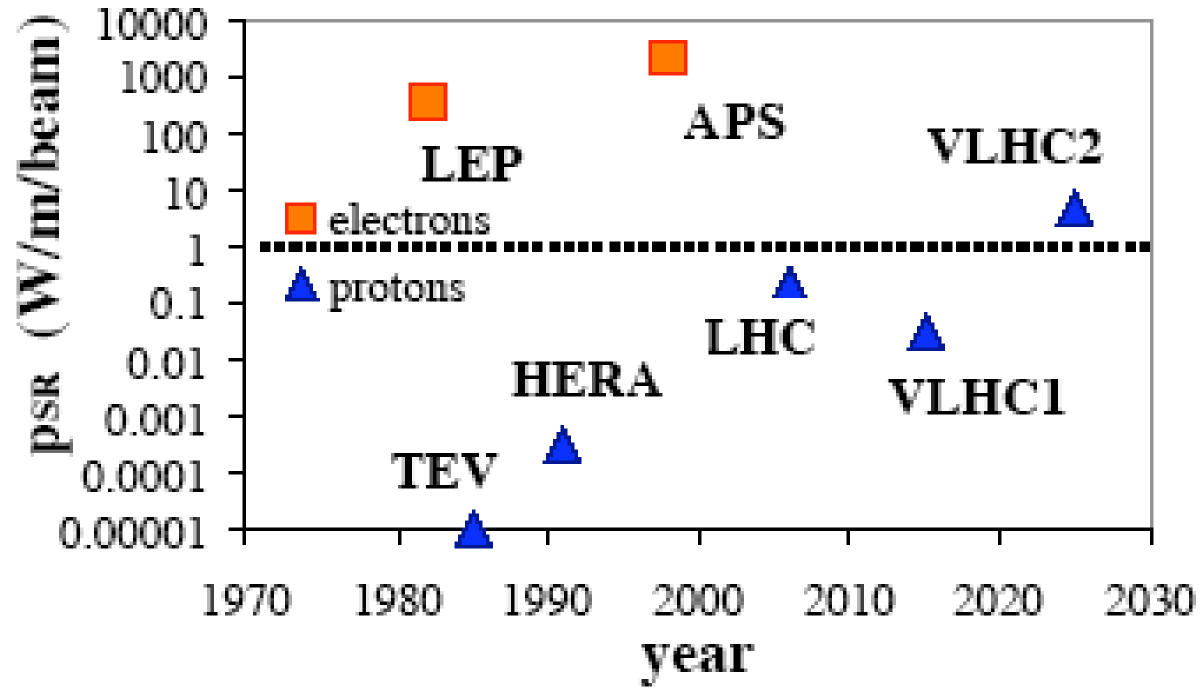
Stage-2 Cost & Performance

- **What are the general design ideas that exist for magnets for the Stage 2 VLHC?**
- **We did not make a cost estimate of the Stage 2 VLHC, but we tried to understand major cost sensitivities.**
  - For example, how does the cost vary as a function of magnetic field?
- **After the "Study," we did some work to help understand the limitations of Stage 2 performance.**
  - Does synchrotron radiation put limits on performance, or does it influence the choice of magnetic field?
- **These questions were studied to help guide future R&D.**

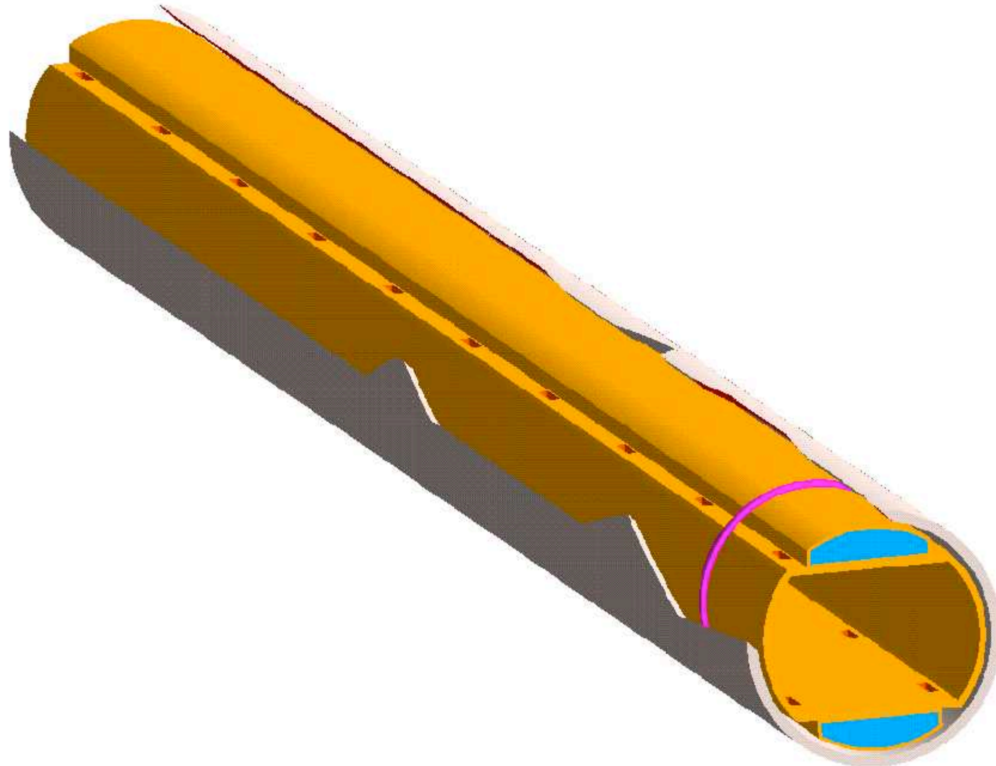
VLHC Cost based on SSC cost distribution



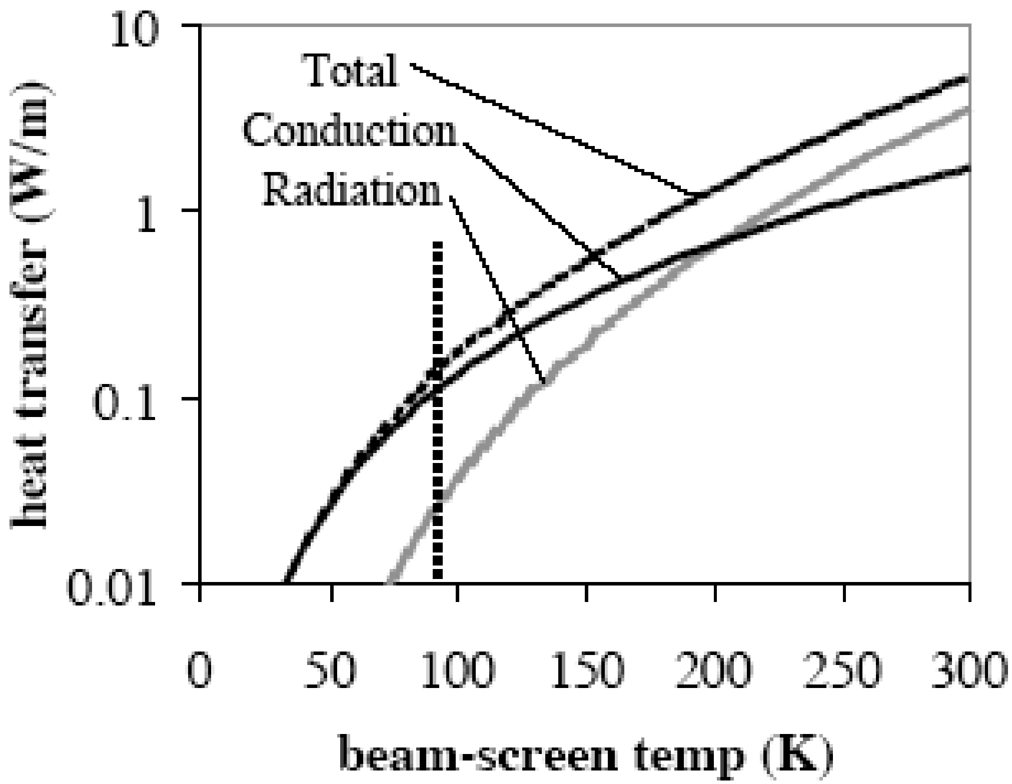
Synchrotron radiation power per meter

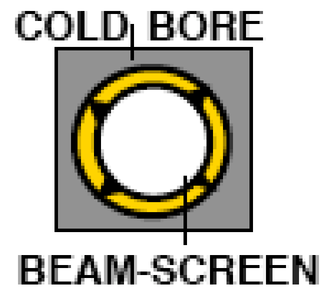


VLHC Beam Screen

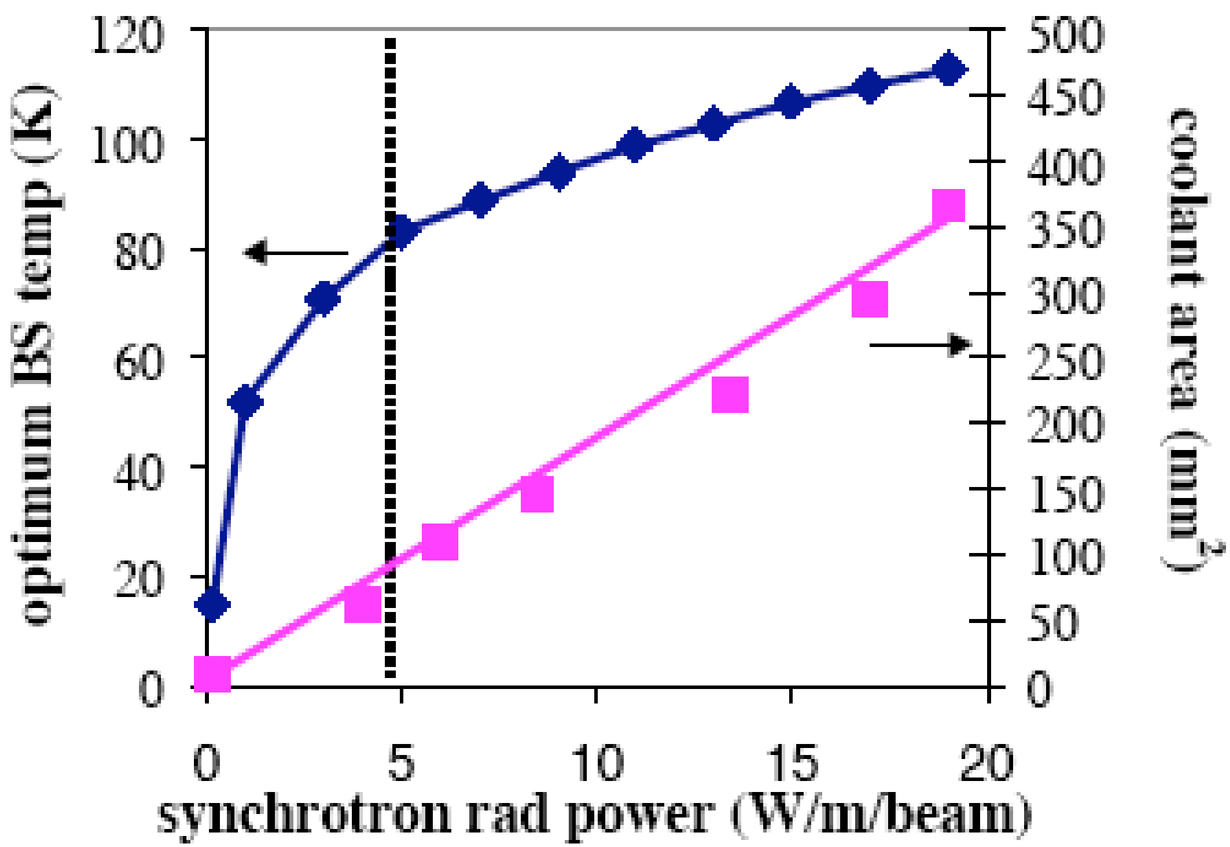


Beam Screen Heat Transfer



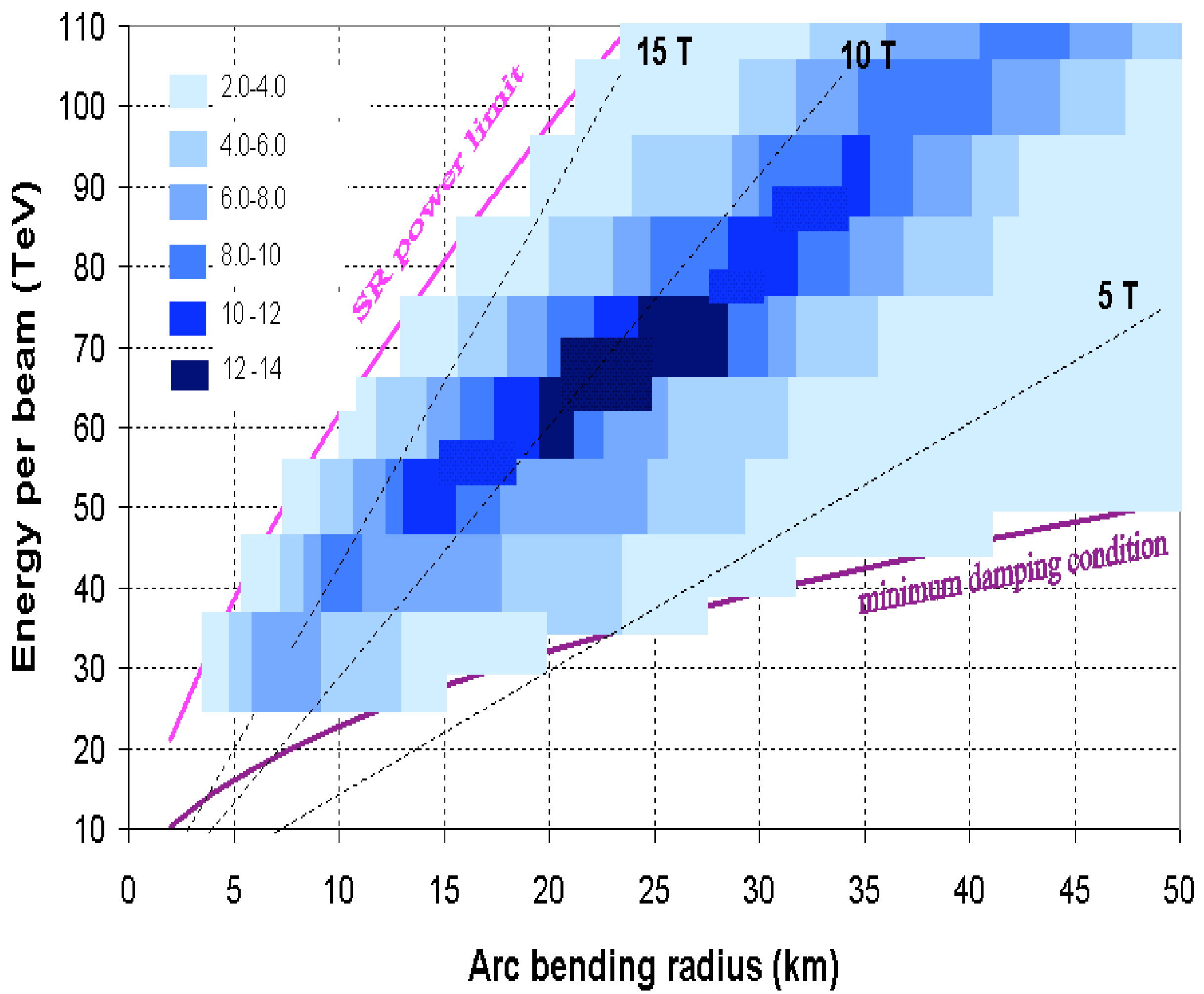


Optimum BS temperature & coolant flow



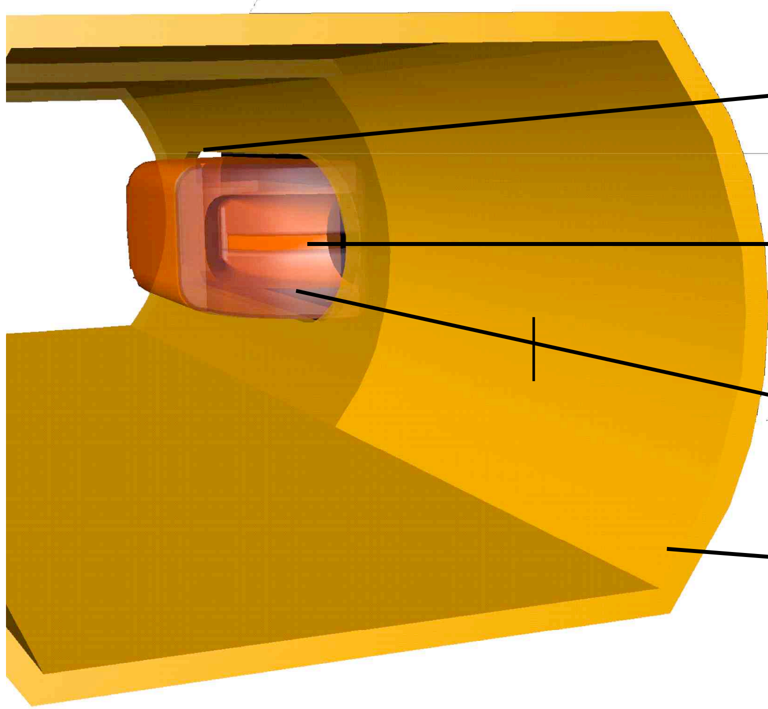
VLHC Optimum Field

P_{SR}<10 W/m/beam peak $t_L > 2\ t_{sr}$ Int/cross < 60   L units $10^{34}\ cm^{-2}s^{-1}$

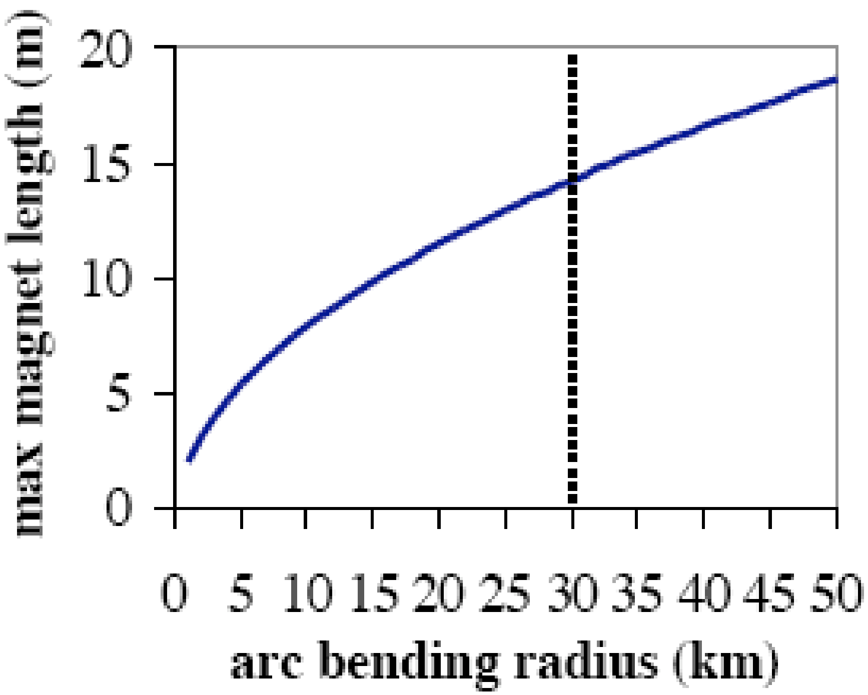


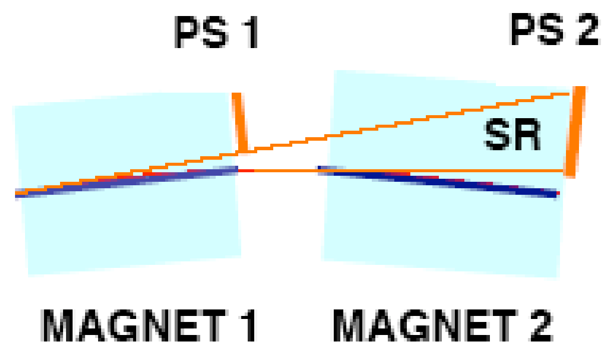
Photon Stops

- Synchrotron radiation masks look promising. They decrease refrigerator power and permit higher energy and luminosity. They are practical only in a large-circumference tunnel.

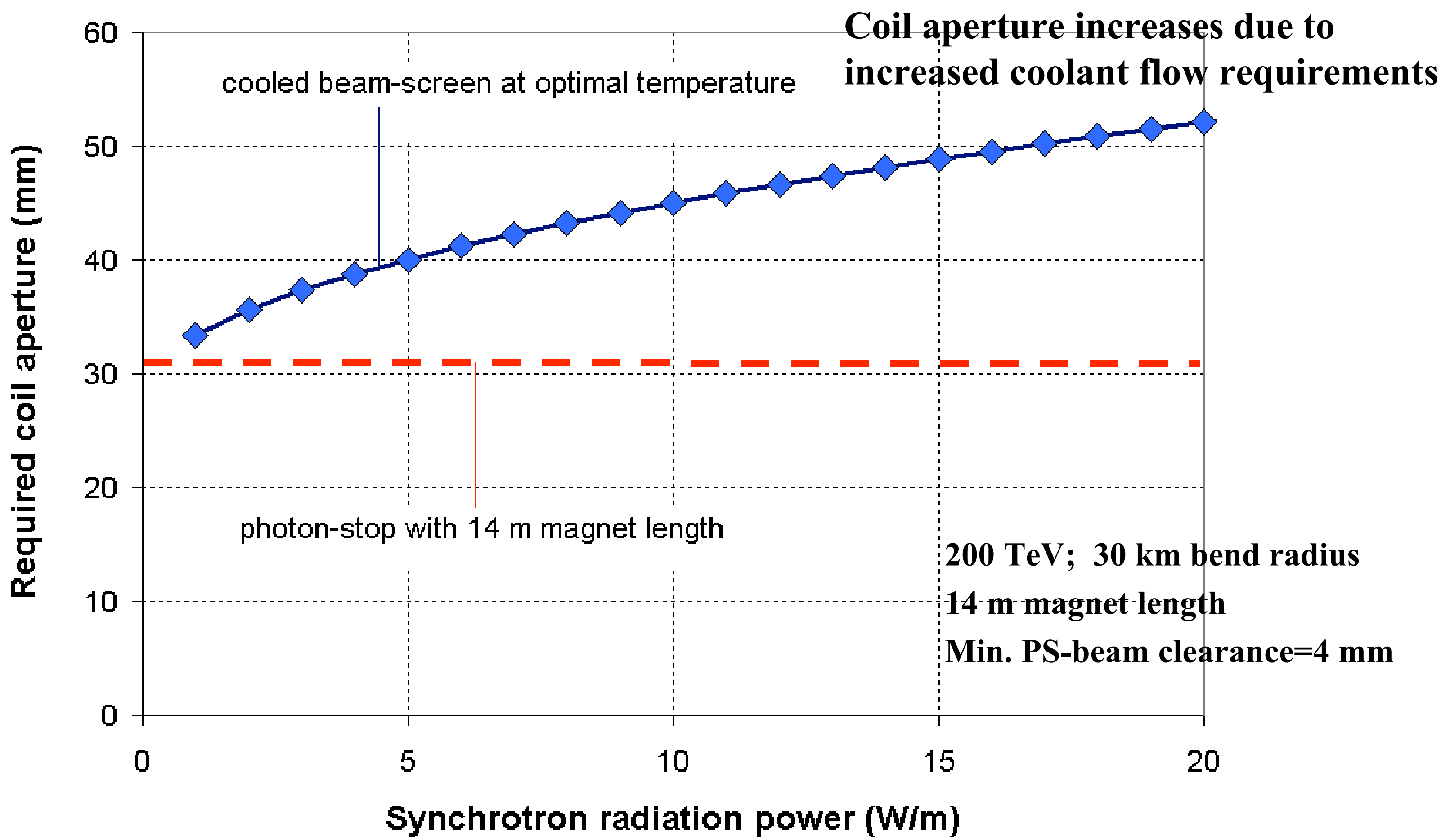


Maximum magnet length vs. bend radius with photon stops

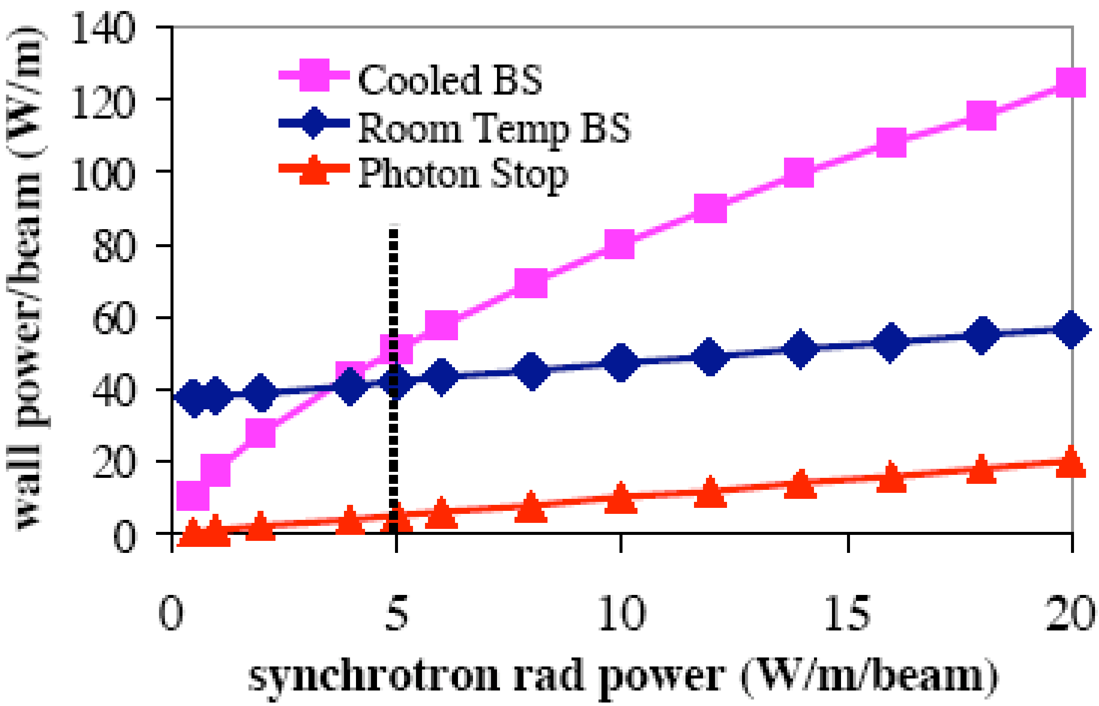


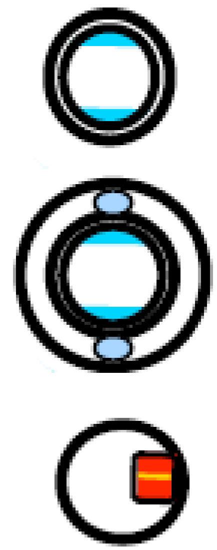


Magnet aperture required for beam screen and photon stops



Wall power vs. synchrad power for various concepts





Very Large Hadron Collider

Photon Stops Test

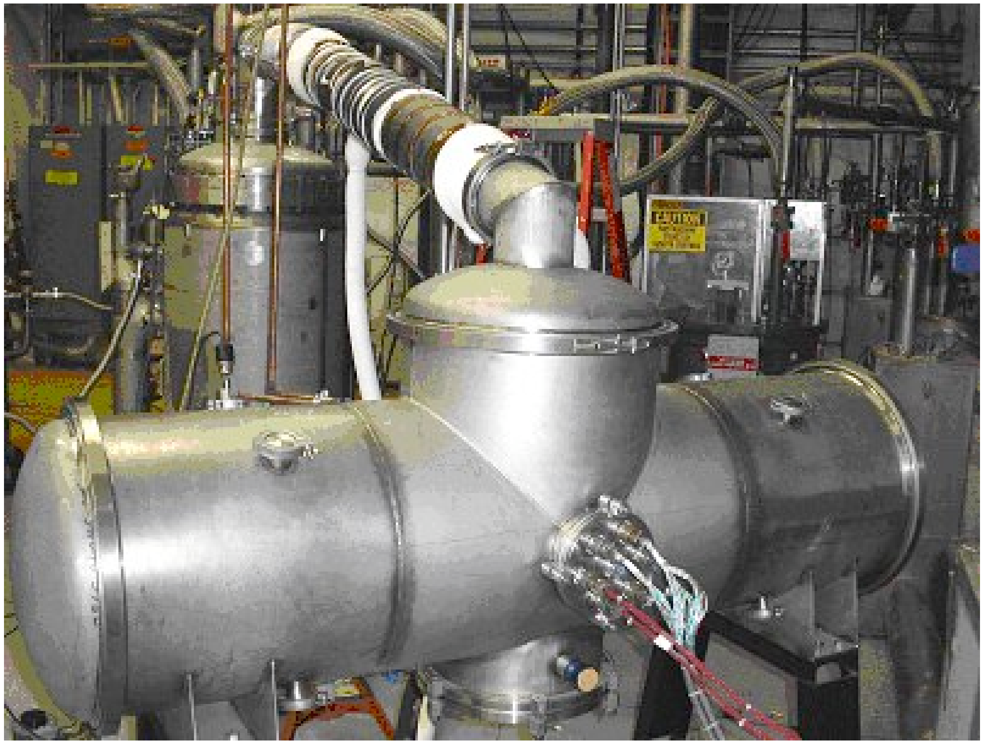
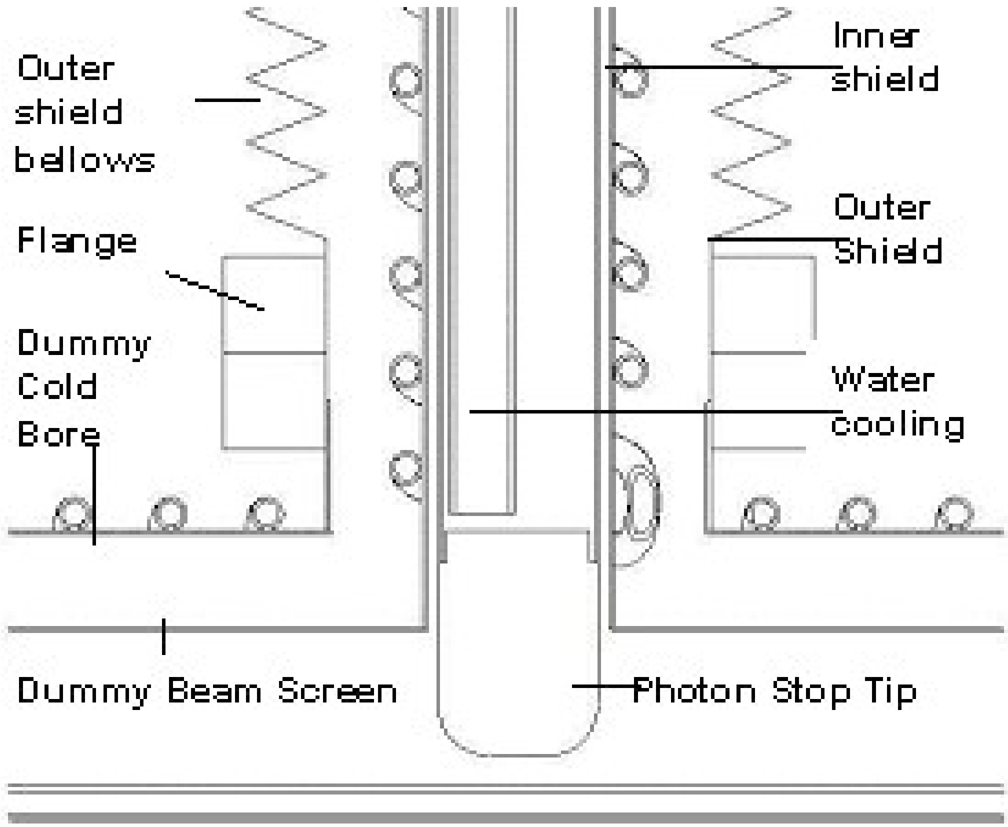
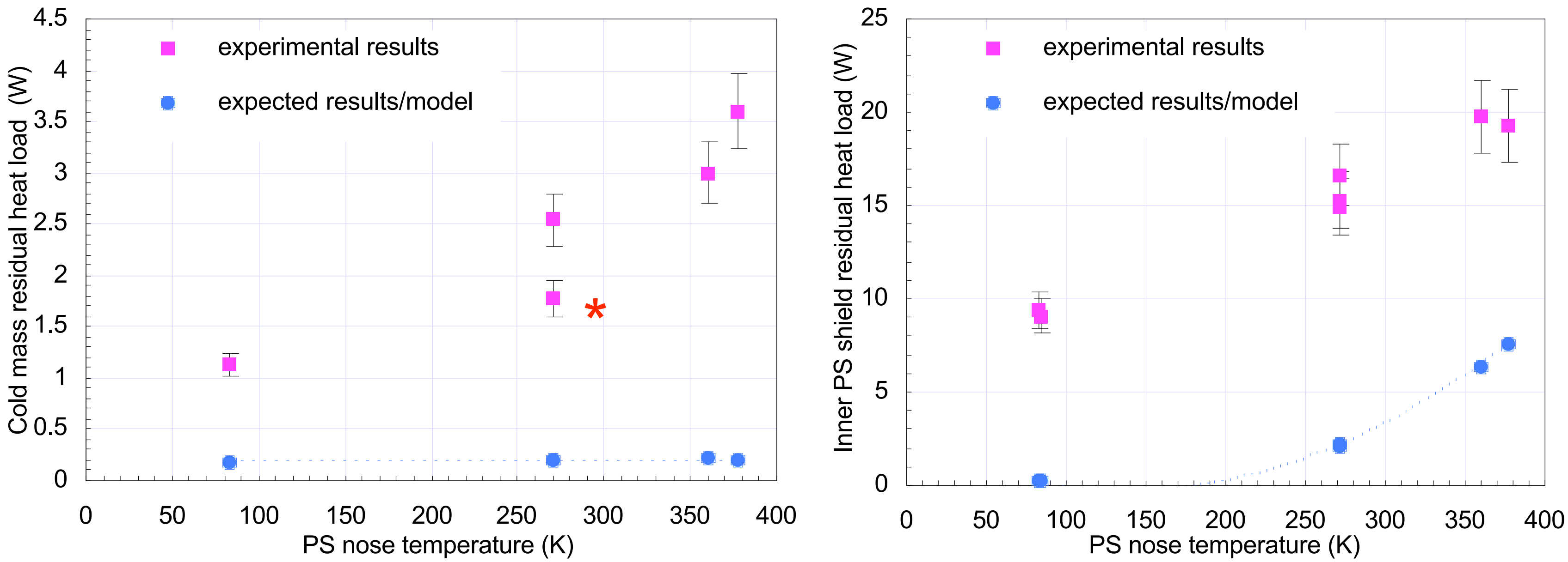


Diagram of photon stop test



Photon Stop Test Results



Stage-2 VLHC Conclusions

- The Stage 2 VLHC can reach 200 TeV and $2x10^{34}$ or more in the 233 km tunnel. This corresponds to 5 W/m of synchrad power.
- A large-circumference ring is a great advantage for the high-energy Stage-2 collider because it allows photon stops.
- Photon stops may permit much greater synchrad power, and, hence, much greater luminosity.
- A small-circumference (i.e. high field) high-energy VLHC may not be realistic.
  - The optimum magnetic field for a 100-200 TeV collider is less than the highest field strength attainable because of synchrotron radiation, total collider cost and technical risk.
- The minimum aperture of the magnet is determined by beam stability and synchrotron radiation, not by field quality.
- There is the need for magnet and vacuum R&D to demonstrate feasibility and to reduce cost.
  - **This R&D will not be easy, will not be quick, and will not be cheap.**

A Word About R&D

- **If we ever want a VLHC, we have to keep at the R&D, particularly for high- and low-field magnets, tunneling and vacuum.**

- **The machines we are talking about are very costly and very complex.**
  - Mistakes and delays are potentially very damaging financially, politically and scientifically.
  - It takes longer than you think to develop the components of a cutting-edge collider.

- **The R&D investment for future HEP instruments will be much greater than we are accustomed to.**

Additional Notes

- The most important requirement for the survival of HEP is worldwide cooperation resulting in a global strategy based on a visionary science roadmap.
- **Sell the science, not the instruments**
    - Learn from the NASA strategy, in which the goals are truly large and visionary, and the instruments are missions along the way.
- The parameters and schedule for a VLHC will depend on the timing and location of all other large facilities. The global plan should recognize these couplings.
- If we ever want to build a VLHC, or any other very large facility, we need to have a vigorous R&D program now.
    - The R&D is very challenging, and the penalty for failure will be severe.

Last Slide