First, a little recent history

- After Snowmass-1996, we had the following plan
  - A VLHC of 100 TeV (center-of-mass)
  - Three different magnets - 1.8 T, 9.5 T and 12.5 T
  - Three different rings - 650 km, 140 km, 105 km

- More recently, we devised a new model for the VLHC
  - If we are willing to accept a decades-long program, low-field and high-field approaches are not adversarial - they support each other
    - This was the Main Ring/Tevatron and LEP/LHC approach, and, if the first step is appropriate, and if an upgrade path is possible, it is the best use of resources

The Concept

- Take advantage of the space and excellent geology near Fermilab
  - Build a BIG tunnel, the biggest reasonable for the site
  - Fill it with a cheap collider
  - Later, upgrade to a higher-energy collider in the same tunnel
    - This spreads the cost, and, if done right, enables exciting energy-frontier physics at each step
    - It allows more time for the development of cost-reducing technologies and ideas
    - 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 a synchrotron radiation-dominated collider, and tunneling can be relatively cheap.

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, $L_{peak}>10^{35}$ in the same tunnel
  - The report is due in May, 2001.
  - The Report will include some estimates of the ranges of expected costs of the major cost drivers for Stage 1. <u>But it is not a cost estimate for Stage 1 of a VLHC!</u>
  - BNL and LBNL are involved, particularly in accelerator physics, magnets, vacuum systems, feedback
  - We hope to have international involvement, probably, at this late date, as reviewers of our work.

The VLHC Study

- **Leader** **Peter Limon**
- **Deputy** **Bill Foster**
  - Accelerator Physics — Mike Syphers & Steve Peggs (BNL)
  - Magnets & Cryogenics — Jim Strait & Steve Gourlay (LBNL)
  - Accelerator Systems — Bill Foster & Alan Jackson (LBNL)
  - Injectors — Phil Martin
  - Conventional Construction — Peter Garbincius
  - Editors — Ernie Malamud & Peter Limon
- **Plus, a cast of thousands!**
- **First drafts of chapters with many "place holders" were due on February 14. Many of them were actually submitted on time! Most of them were way too detailed and long!**
- **Now we have to settle some AP and technical issues and agree on descriptions of each collider.**

Some Details

- There are many possibilities for staging
- Favored at Fermilab now is an ~240 km tunnel
  - This seems possible in the Fermilab area
- Fill it with superferric magnets, ~2 T, yielding a 35 TeV - 40 TeV (cm) collider *(we believe this is least costly, but that remains to be shown - one of the goals of the Study)*
- Later, 10 T magnets results in E ~ 175 TeV (cm). It could go higher, but synchrotron radiation or IP radiation and power may limit the energy
  - By the way, a 240 km tunnel will easily support a 300 GeV (cm), 10^{34} e^+e^- collider, or a top factory, with an affordable power cost

Some advantages of this scheme

- **Each step yields new and interesting physics**
- **Each step is a minimum cost step, even though the total cost to get to E>100 TeV may not be minimized by this scheme**
- **There are many accelerator physics advantages**
  - A superferric magnet permits injection from Tevatron
  - Injection at high energy eliminates magnetization and stability issues in the high-energy collider
  - Single turn injection is simple and fast, maximizing integrated luminosity
  - The initial technology is straightforward, minimizing necessary R&D
  - Time is made available for the R&D necessary to solve problems and reduce cost of high-energy phase
- **The plan is flexible in particle type (pp or e^+e^-), final energy, and experiments**

Some disadvantages of this scheme

- It takes longer to get to the highest energy - maybe
- It may cost more (though not necessarily) to get to the highest energy
  - 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 and cheaper - the Study might illuminate this issue
- There are some accelerator physics disadvantages
  - The balance between total synchrotron radiation power and emittance damping may not be optimal
  - The initial low-energy design has to correctly predict many details of the final high-energy design
  - The beam injected into the high-field collider can cause damage to the machine
- The plan starts with a very big tunnel, which may have some political difficulties

Primary Parameters for a Staged VLHC

From the Director's charge	Stage 1	Stage 2
Minimum E_{cm} [TeV]	30	150
Peak Luminosity [$cm^{-2}s^{-1}$]	10^{34}	2×10^{34}

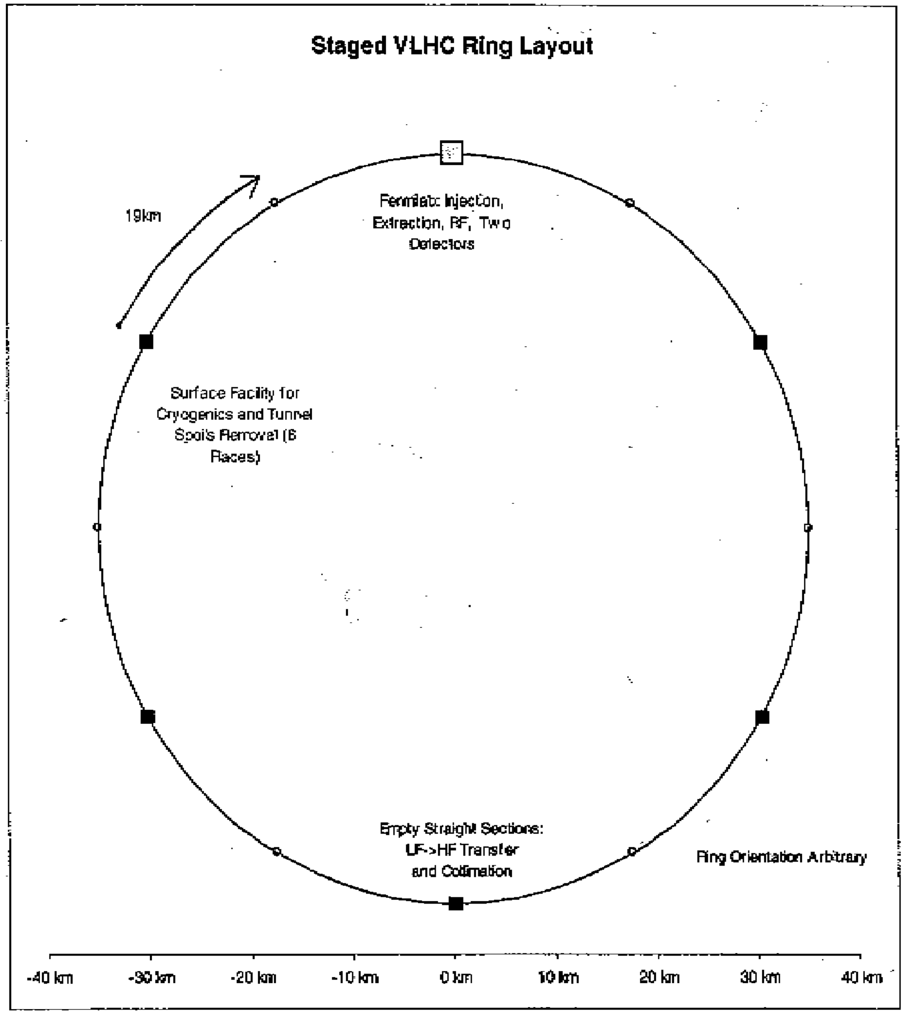
Located at Fermilab, Injection from the Tevatron

Additional Parameters		
Average R_{arc} [km]	35.0000	35.0000
Construction period	10 years	
Maximum annual obligations	$1 Billion	

Parameters for a Staged VLHC

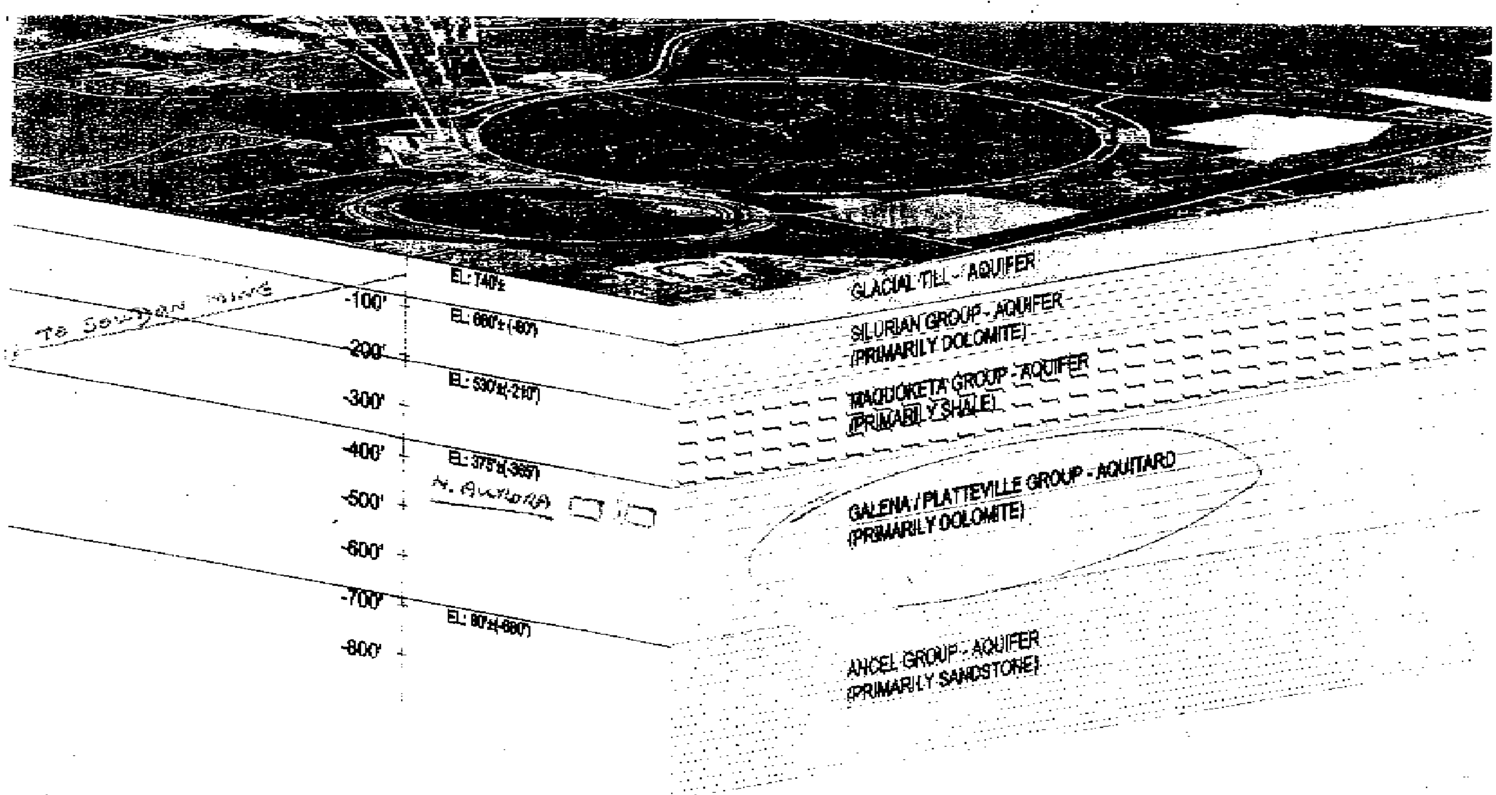
	Phase 1		Phase 2
E_{cm} [TeV]	40		175
Peak Luminosity [cm^{-2} s^{-1}]	10^{34}		$2x10^{34}$
$Circ_{total}$ [km]		233	
B_{dipole} [T]	1.9		9.4
Arc packing factor	~95.0%		~83.0%
Average R_{arc} [km]		34.961	
Half-cell length [m]		135.486	
Number of half cells		1720	
Number of dipoles	3440		9728
Length of dipoles [m]	65		16
Bunch spacing [ns]		18.8	

Very Large Hadron Collider



NuMI MINOS

Geologic Setting



"This simple, well understood, bedrock geology is outstanding for tunneling." SSC Site Evaluation Summary - SSC Site Task Force, DOE/ER-0392, November 1988.

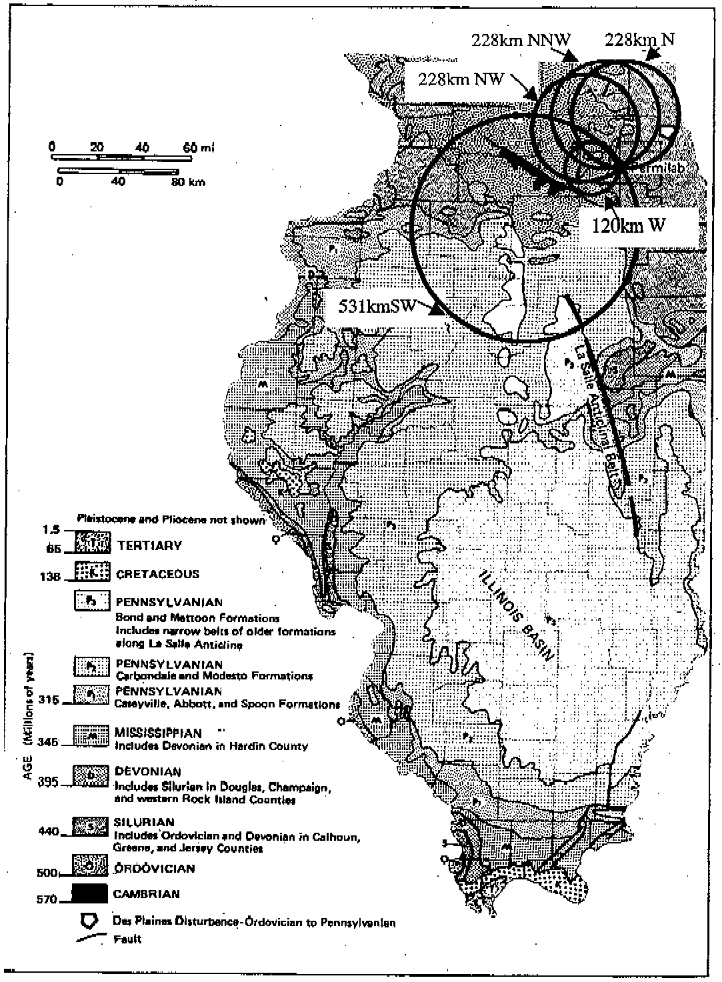


Figure 13: Possible VLHC Alignments

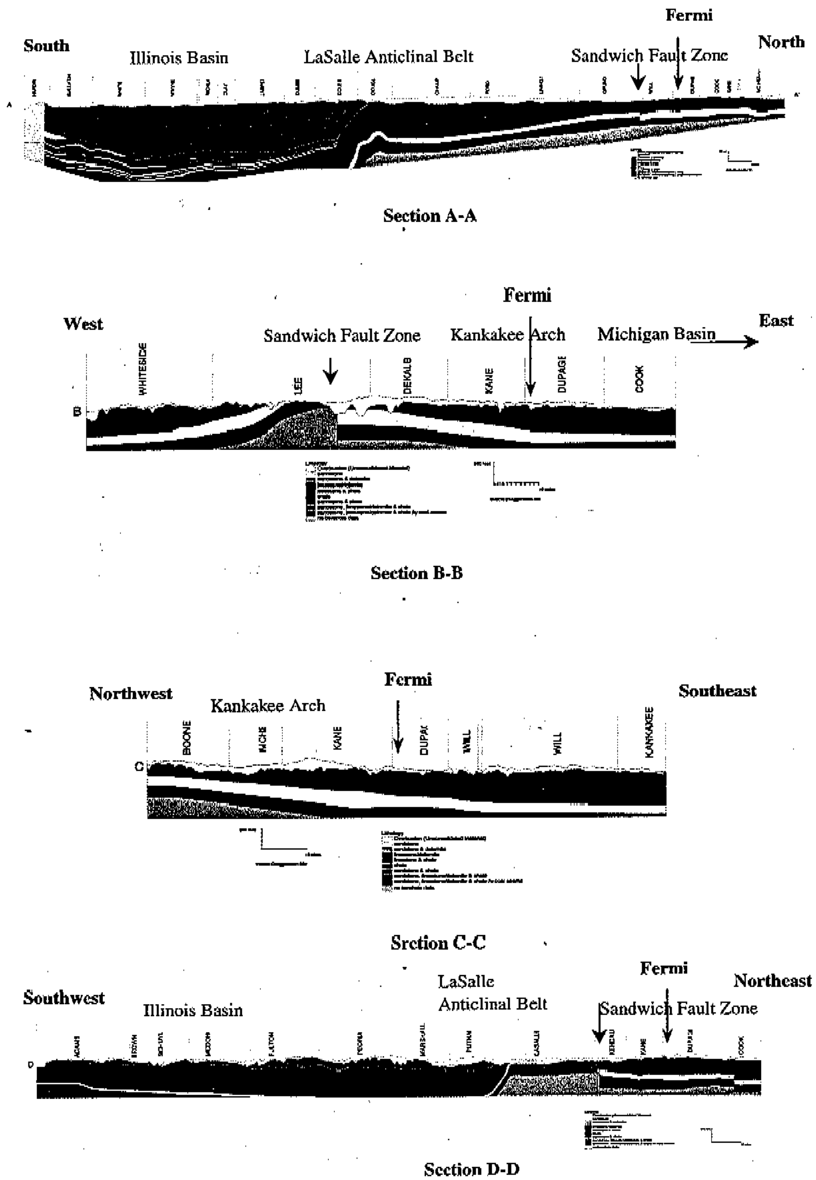
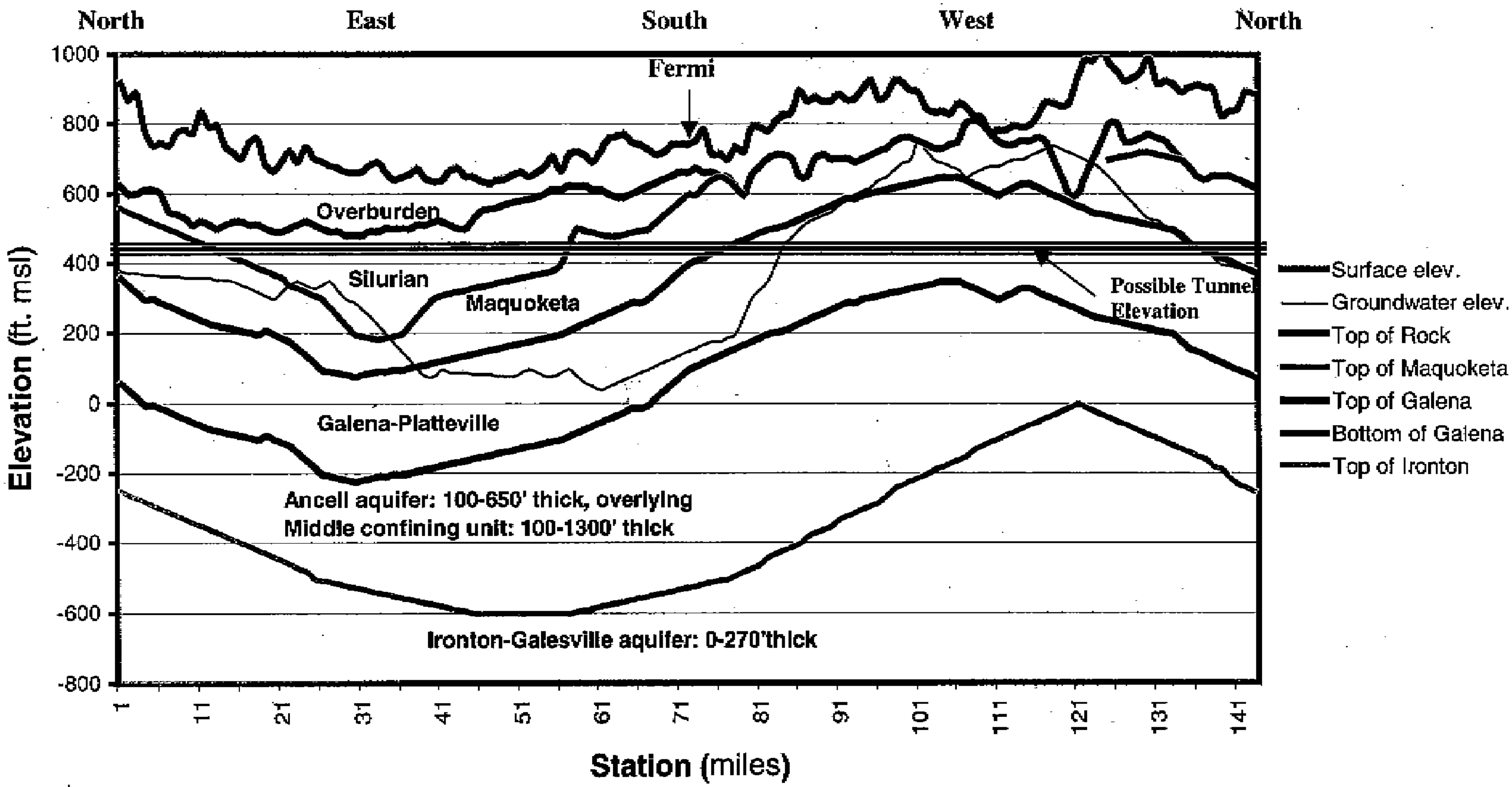


Figure 4: Geologic Sections, Illinois State Geological Survey

Figure 15: Generalized Geologic Section

~Lampshade

228 km Ring
North of Fermi



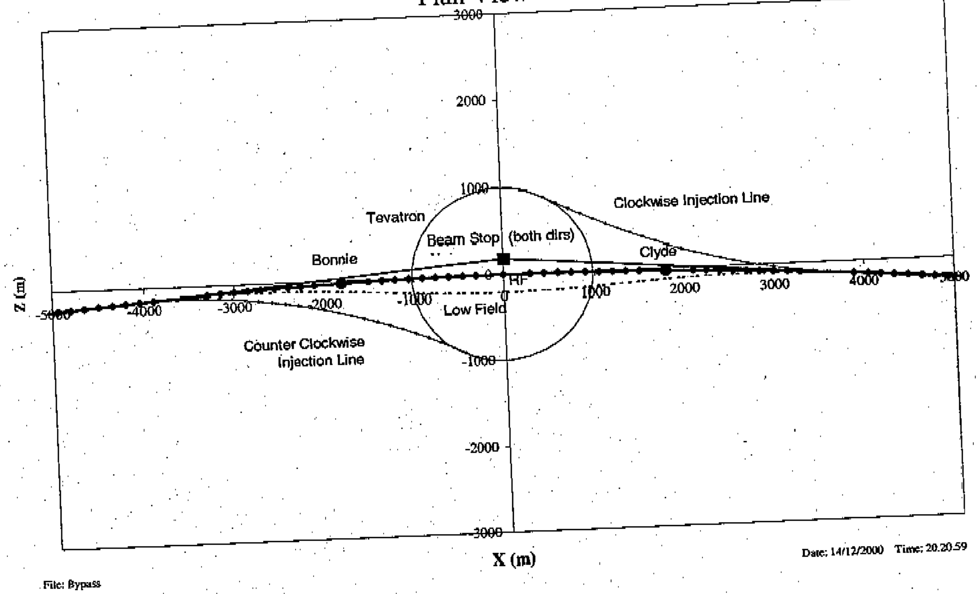
Stage 1 VLHC Parameters

Beta* at interaction point	0.30	m
Total cross section at E_{cm}	1.3×10^{-25}	cm^2
Distance from IP to first magnet	21	m
Interactions/crossing	26	
Injection energy from Tevatron	900	GeV
Fill time from Tevatron	60	mins
Acceleration time	1000	s
Fraction of buckets filled with beam	90	percent
Normalized emittance (rms)	$1.5\pi \times 10^{-6}$	m
Particles/bunch	2.5×10^{10}	
Beam current	1.9×10^{-1}	A
Minimum tunnel diameter	3.6	m
RF frequency	477.938	MHz
RF Voltage	50	MV
Bunch length at injection (rms)	5.5	cm
Bunch length at collision (rms)	2.7	cm

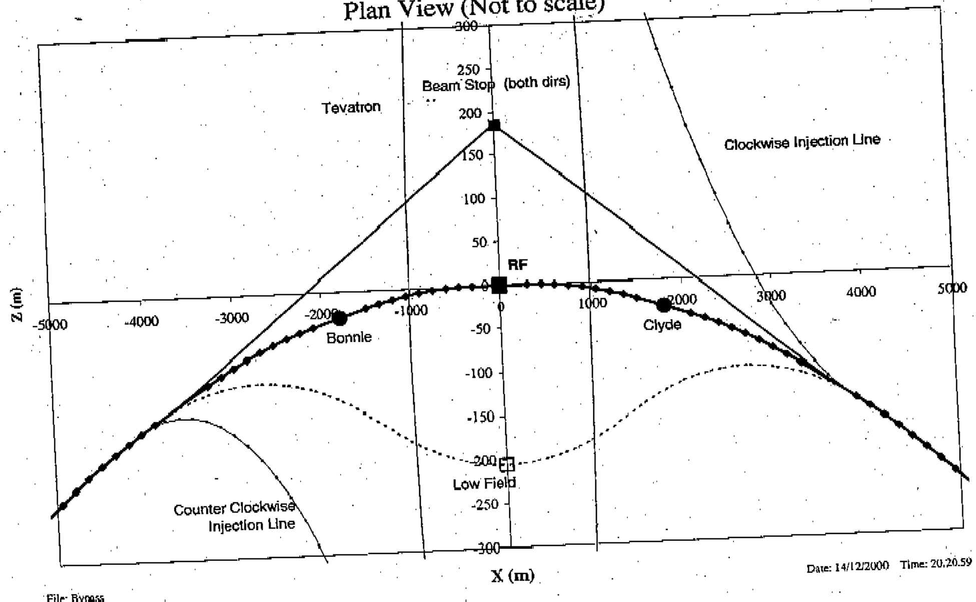
Stage 2 VLHC parameters

Beta* at interaction point	0.50	m
Total cross section at E_{cm}	1.5×10^{-25}	cm^2
Distance from IP to first magnet	30	m
Interactions/crossing	60	
Power from beam-beam inelastic collisions	40	kW
Injection energy from Stage 1	10	TeV
Fill time from Tevatron	30	s
Acceleration time	2000	s
Fraction of buckets filled with beam	90	percent
Normalized emittance (rms)**	$0.08\,\pi \times 10^{-6}$	m
Particles/bunch (at peak luminosity)	5×10^9	
Beam current (at peak luminosity)	3.9×10^{-2}	A
SynchRad power/meter/beam	3.5	W/m
Total synch. radiation power (2 beams)	1.3	MW
Magnet length	16	m
Magnets per half-cell	7	

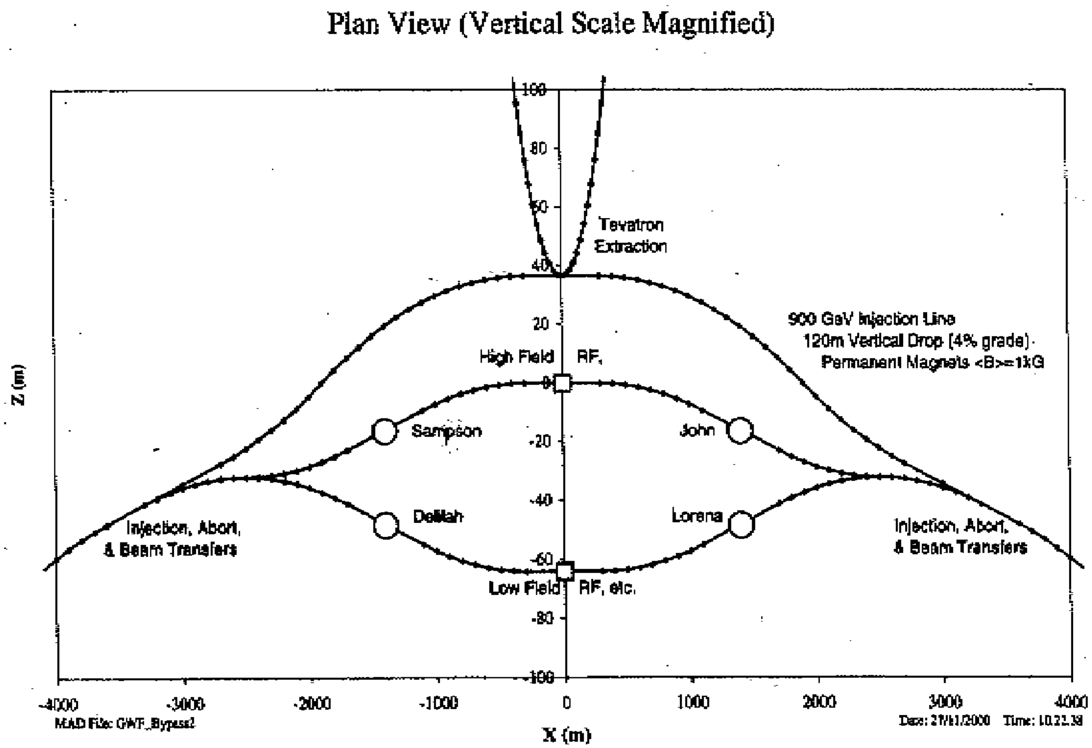
Single On-site Beam Stop
Plan View

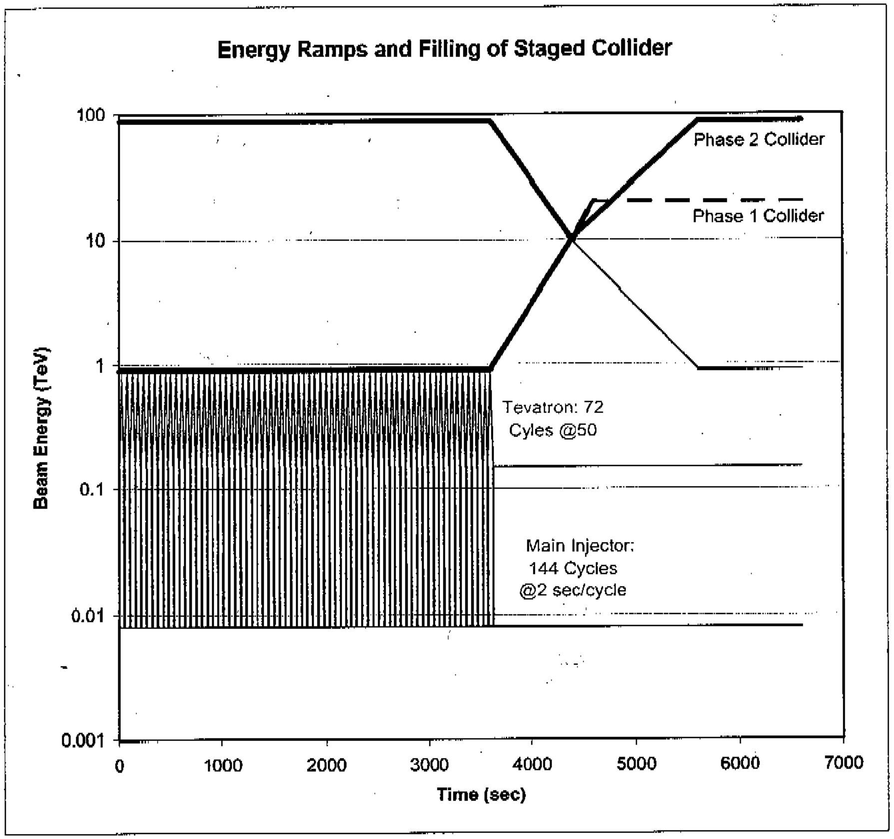


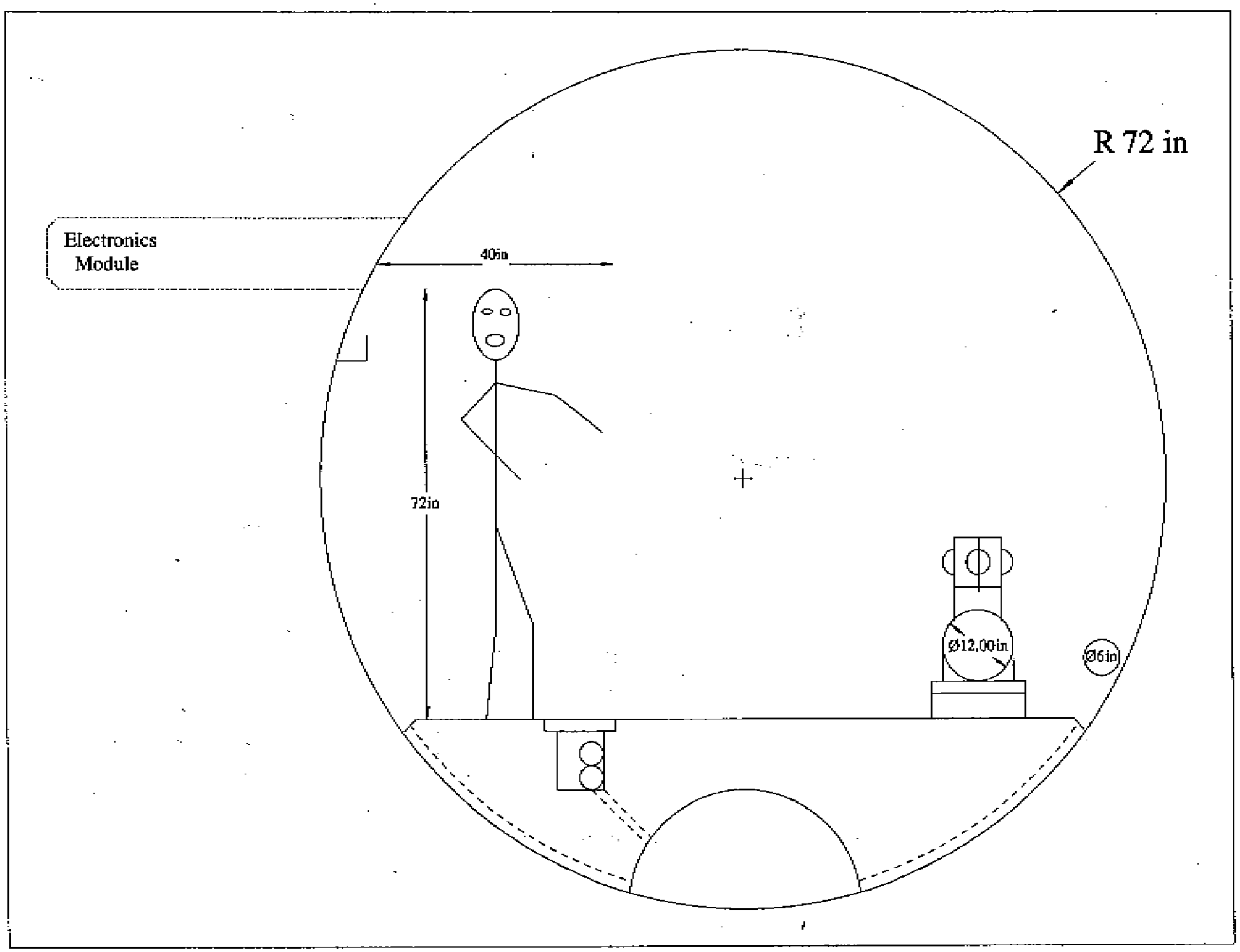
Single On-site Beam Stop
Plan View (Not to scale)

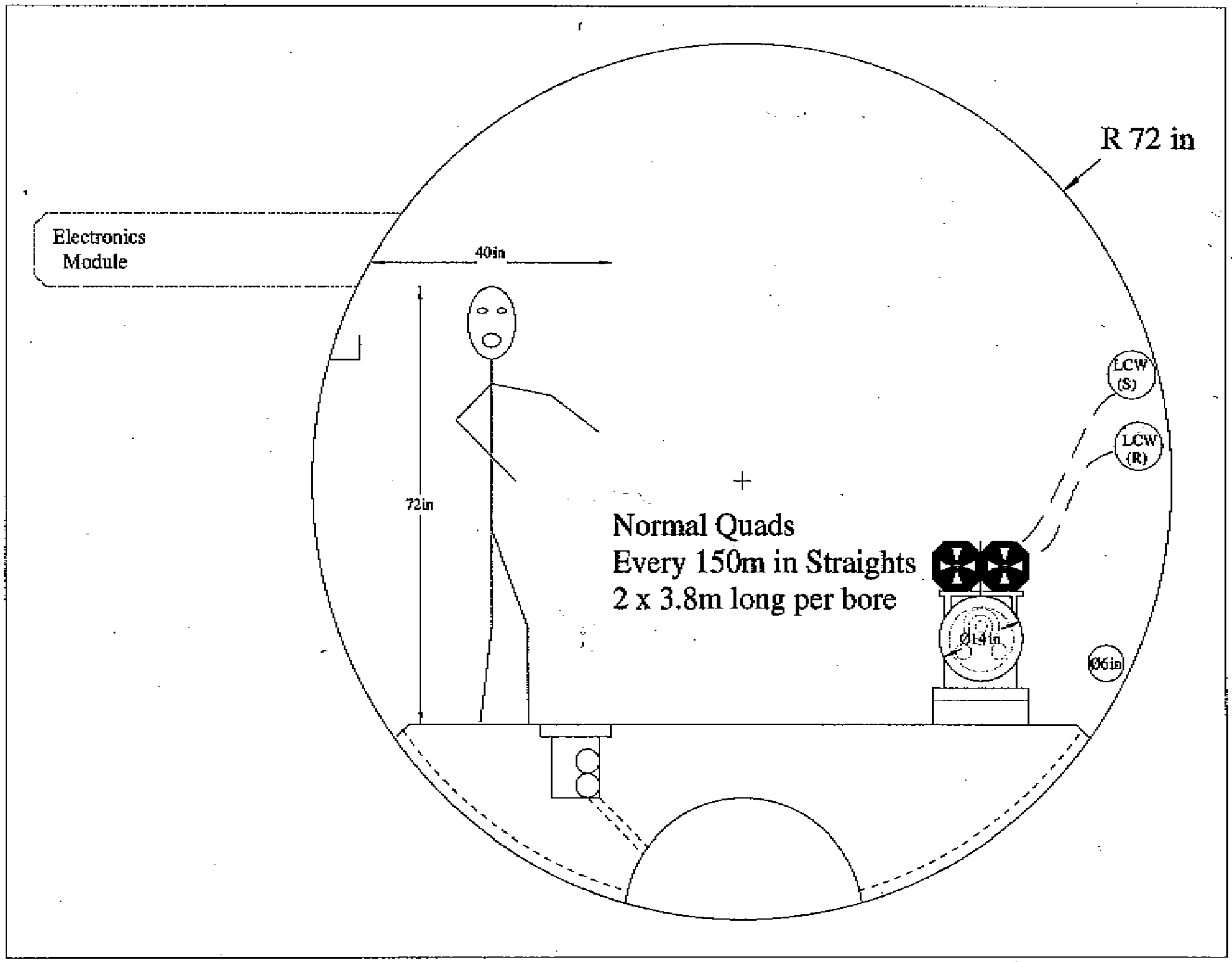


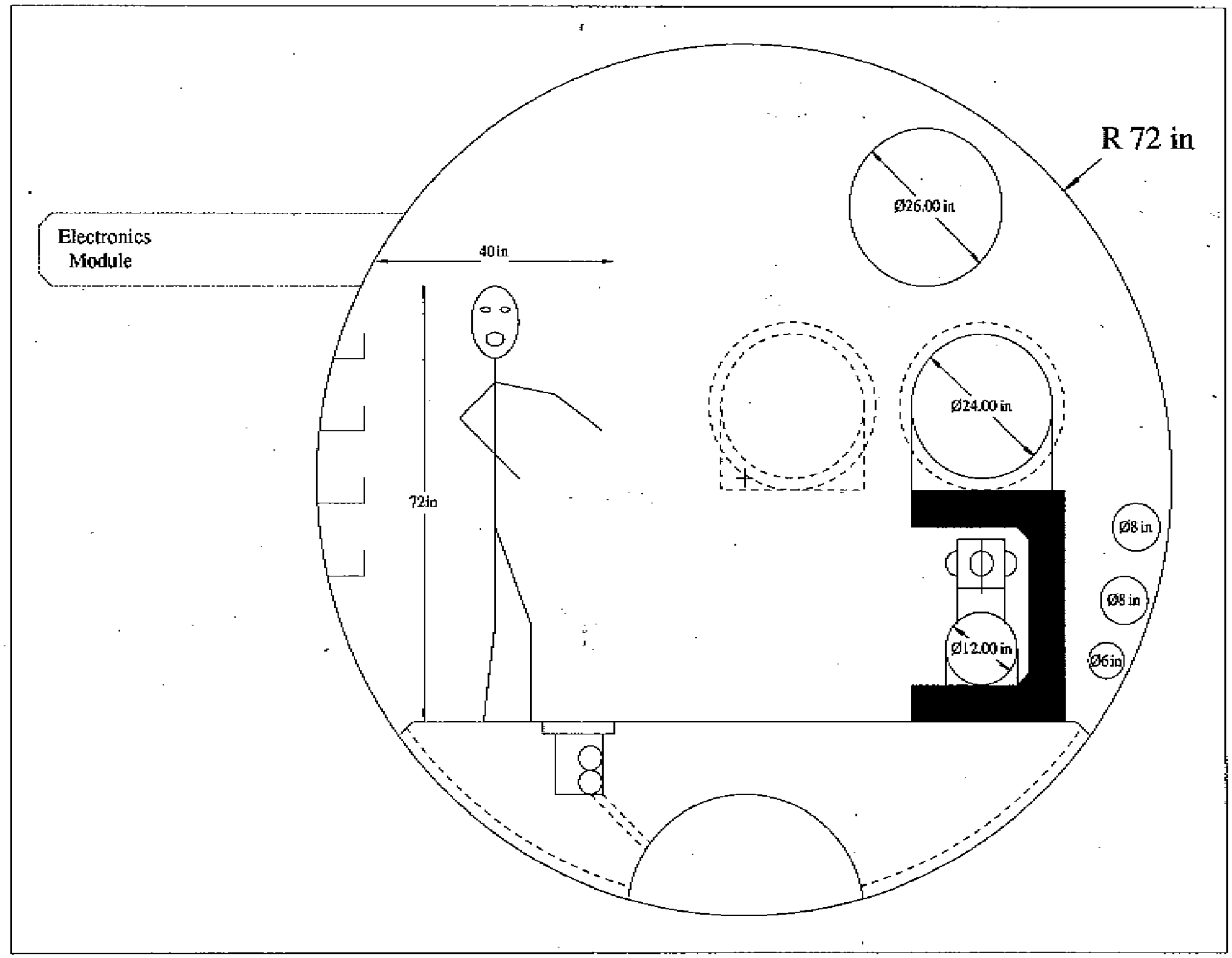
How Two Colliders Coexist in One Tunnel




Energy Ramps and Filling of Staged Collider
100
10
1
0.1
0.01
0.001
Beam Energy (TeV)
0
1000
2000
3000
4000
5000
6000
7000
Time (sec)
Phase 2 Collider
Phase 1 Collider
Tevatron: 72
Cyles @50
Main Injector:
144 Cycles
@2 sec/cycle


R 72 in
Electronics Module
40in
72in
Ø12,00in
Ø6in


R 72 in
Electronics
Module
40in
72in
LCW
(S)
LCW
(R)
Normal Quads
Every 150m in Straights
2 x 3.8m long per bore
Ø14in
Ø6in


R 72 in
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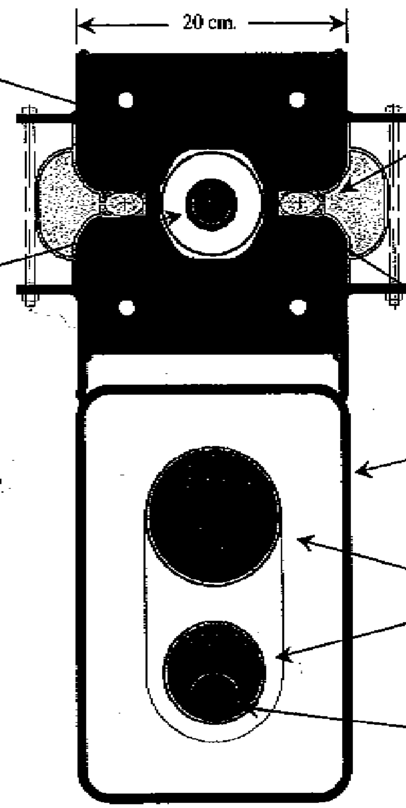
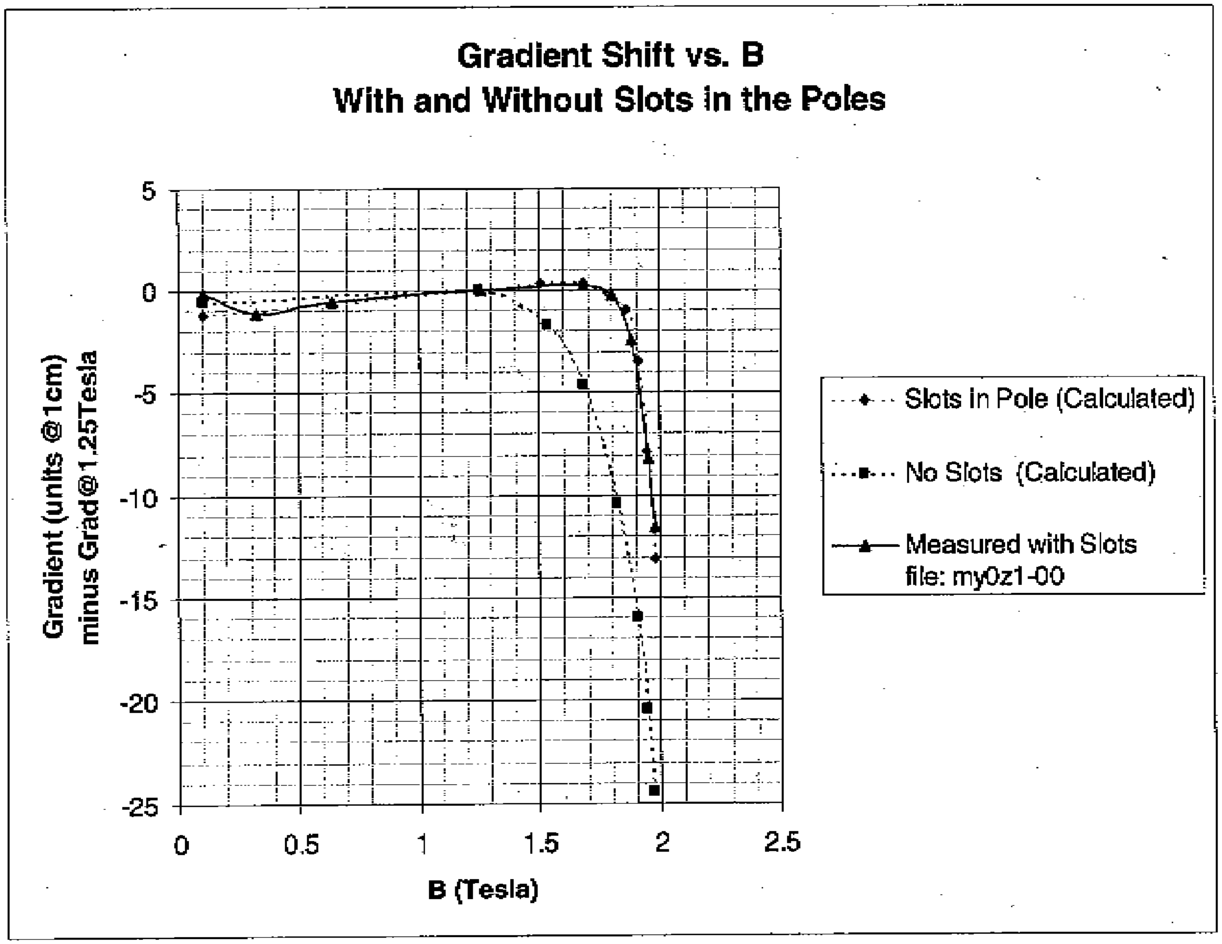
Transmission Line Magnet



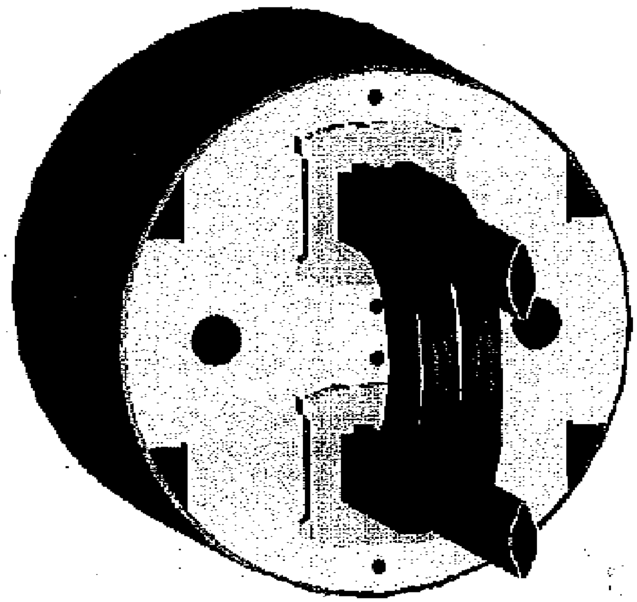
KEY FEATURES:

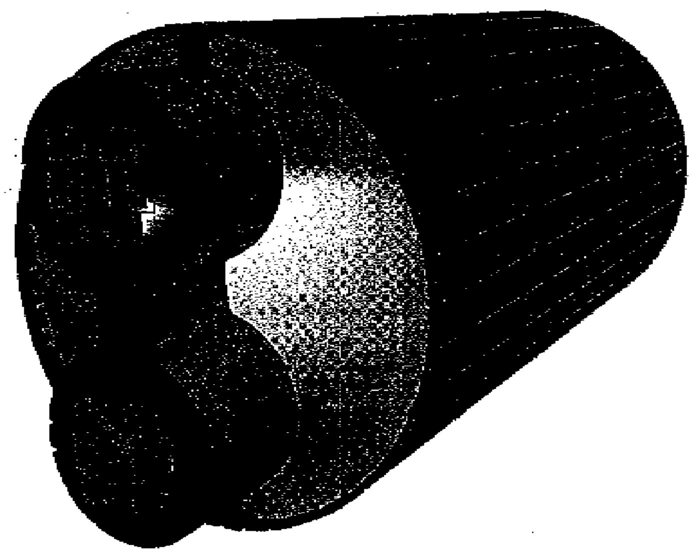
- Simple Cryogenic System
- Small Superconductor Usage
- Small Cold Mass
- Low Heat Leak
- Continuous in Long Lengths
- No Quads or Spool Pieces
- Warm Bore Vacuum System
- Standard Construction Methods

Effect of Slots in Pole on Gradient Shift in Transmission Line Magnet



React & Wind Common Coil Dipoles





-Field: Bmax=11 T @ 4.3 K
-Current: 15.3 kA
-Design: two-layer block type
two-bore common coil
-Hybrid: NbSn - NbTi
-Horizontal bore gap: 30 mm
-Coil cross-section per bore 11.2+15.6 cm^2

-Field: Bmax=10.5 T @ 4.3 K
-Current: 23.8 kA
-Design: one-layer shifted blocks
two-bore common coil
-Cable: 21 mm width (60 0.7 mm strands)
-Horizontal bore gap: 40 (50) mm
-Coil cross-section per bore 26.7 cm^2

Present status (1)

- **We are making progress. Some findings:**
  - 10^{35} luminosity at 175 TeV (initial chosen parameters for the high-energy ring) seems very problematical - IR power > 200 kW/IR
    Refrig power for the liner > 100 MW (@plug) for 100 K liner
    Luminosity lifetime (2 IRs) < 4 hours
  - **We reduced the luminosity goal to 2×10^{34}**
  - Surprisingly, the vacuum was not a problem for the high-energy ring, even at a luminosity of 10^{35}.
- **We have a lot of text, too much, in fact.**
  - There is a LF engineering team in place. They are working away.
  - We have chosen a company to do underground design and cost estimate for three orientations of the tunnel.
  - We have decided how to present the cost estimate - a range of costs for the major cost drivers and a prescription to extrapolate to the total cost.

Very Large Hadron Collider

Present status (2)

- **There are still many issues:**
  - The first issue is to agree on all the parameters of both rings.
  - Those parameters have to be communicated, and all the text and cost estimates have to work be based on those parameters.
  - The text has to be cut down to a reasonable amount. We are aiming at a total of about 200 pages. We have made page guidance for each section.
  - We hope that longer and more detailed papers will be put into sufficiently polished form that they can be indexed and referenced.
  - We are starting the cost estimating exercise.
- **There are many technical issues to settle:**
  - We do not yet have all of the parameters we need for the low-energy ring, such as a complete fabrication and installation model, alignment requirements, engineering models of installation, repair, and so forth.
  - We need to have a finished lattice of the HF ring, including the IRs. This model has to be feasible.

Snowmass 2001

❖ VLHC goals and questions for Snowmass 2001

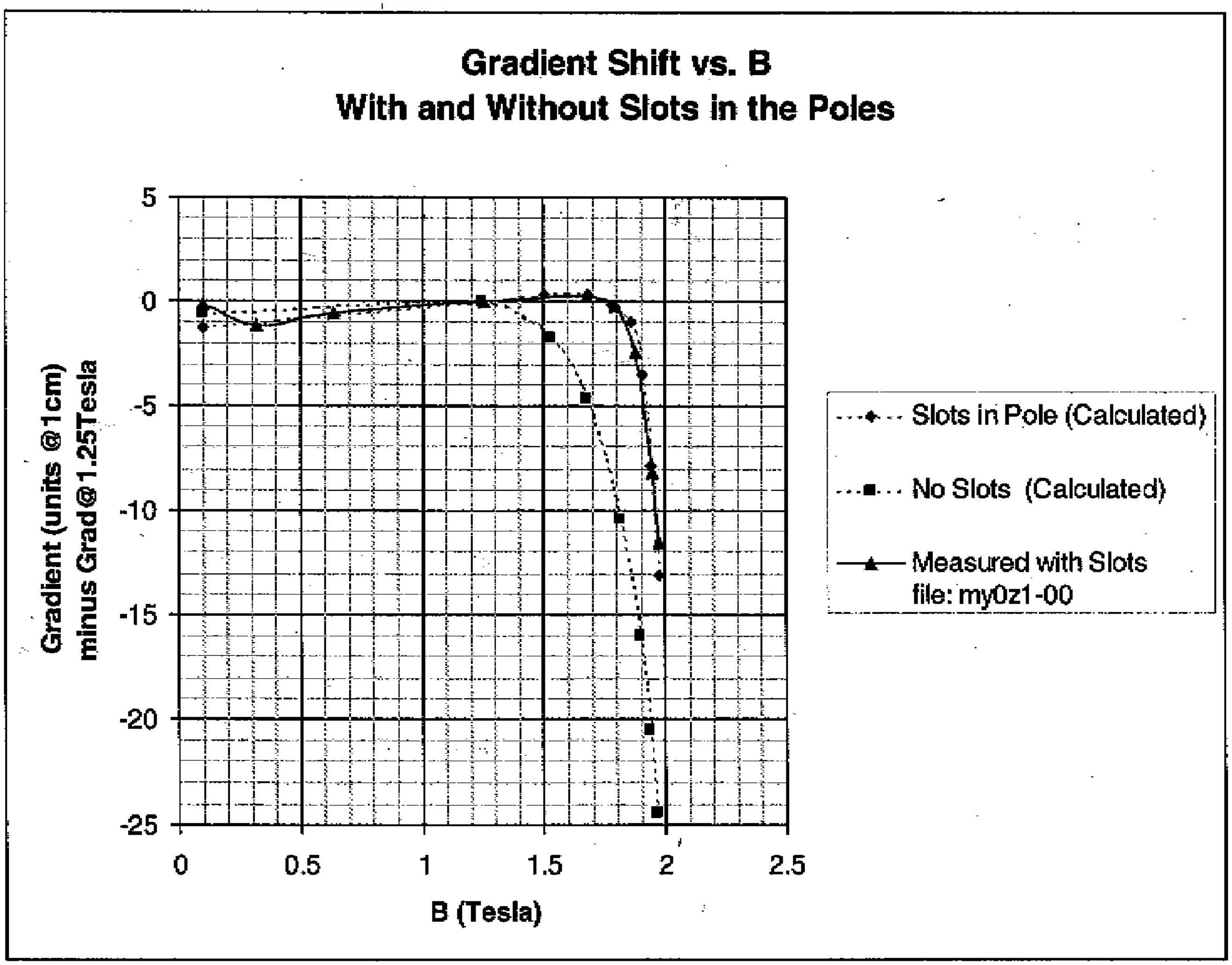
- Our goal will be to fill in, expand and broaden the VLHC Study
  - What other possibilities are there? e^+e^-, smaller tunnels…
  - Are there other staging possibilities?
  - What are the limits to energy and luminosity?
  - What is the R&D program?
  - Can we sensibly distribute the R&D work among the various participants?
  - When (and how!) along the R&D path can we make decisions and establish new directions?
  - What resources and how much time is needed to accomplish the R&D?

VLHC WEB Pages

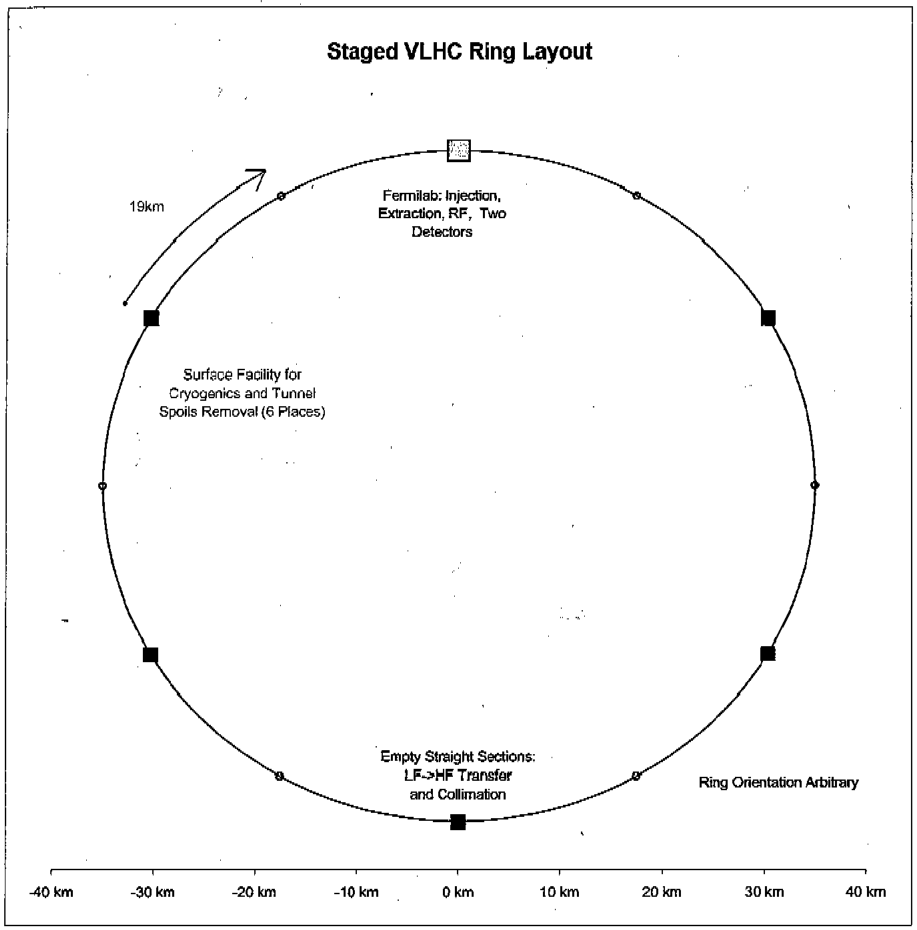
- **References and web pages**

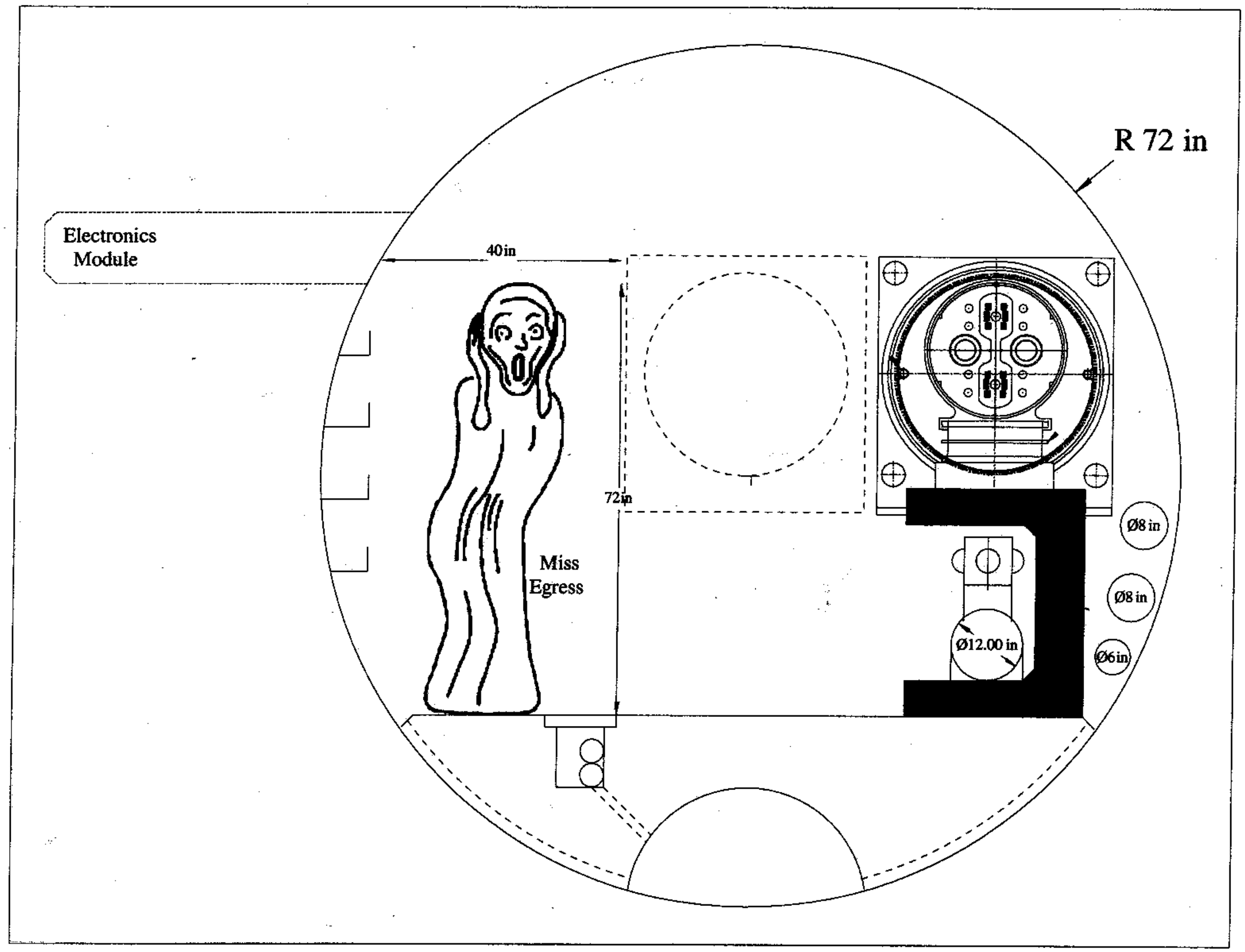
  - Proceedings of the workshops: http://vlhc.org
  - Compilation of papers (Snowmass 96, Gilman Panel, Annual Report etc.) http://www-ap.fnal.gov/VLHC

Effect of Slots in Pole on Gradient Shift in Transmission Line Magnet



*Staged VLHC Parameter List - **DRAFT** Version 0.4 2/23/01*





R 72 in
Electronics
Module
40 in
72 in
Miss
Egress
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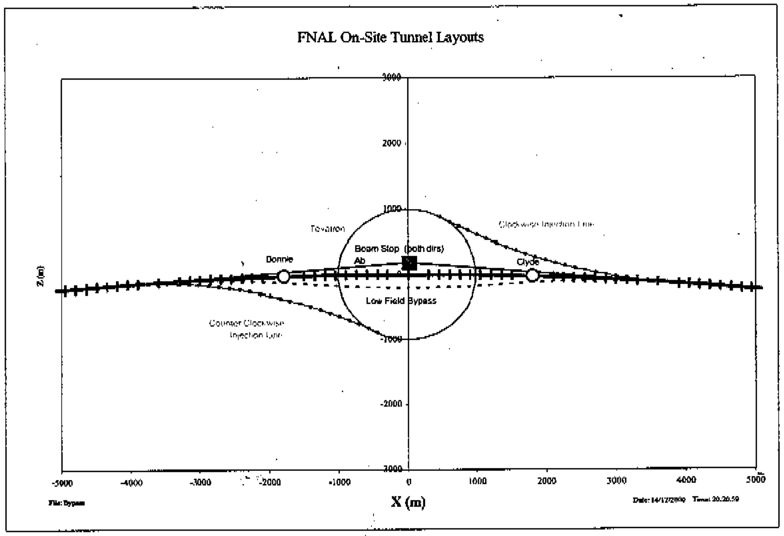
Ø12.00 in


FNAL On-Site Tunnel Layouts
Tevatron
Beam Stop (both dirs)
Ab
Bonnie
Clyde
Clockwise Injection Line
Low Field Bypass
Counter Clockwise Injection Line
Z (m)
X (m)
File: Bypass

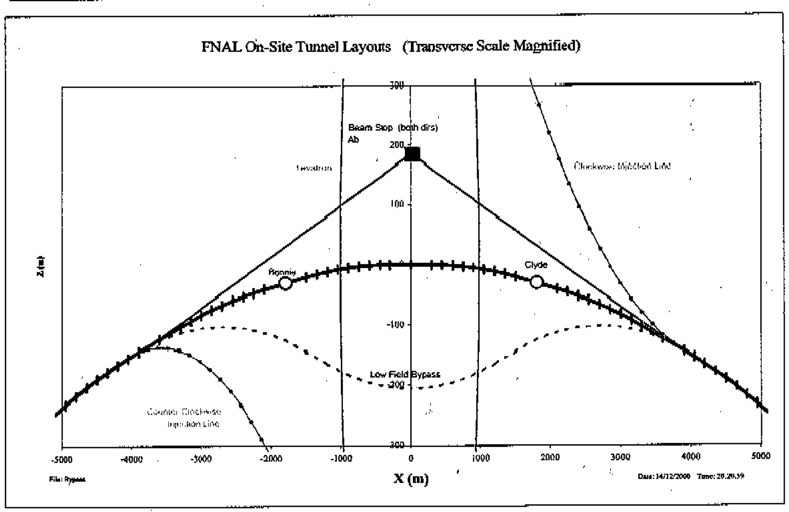
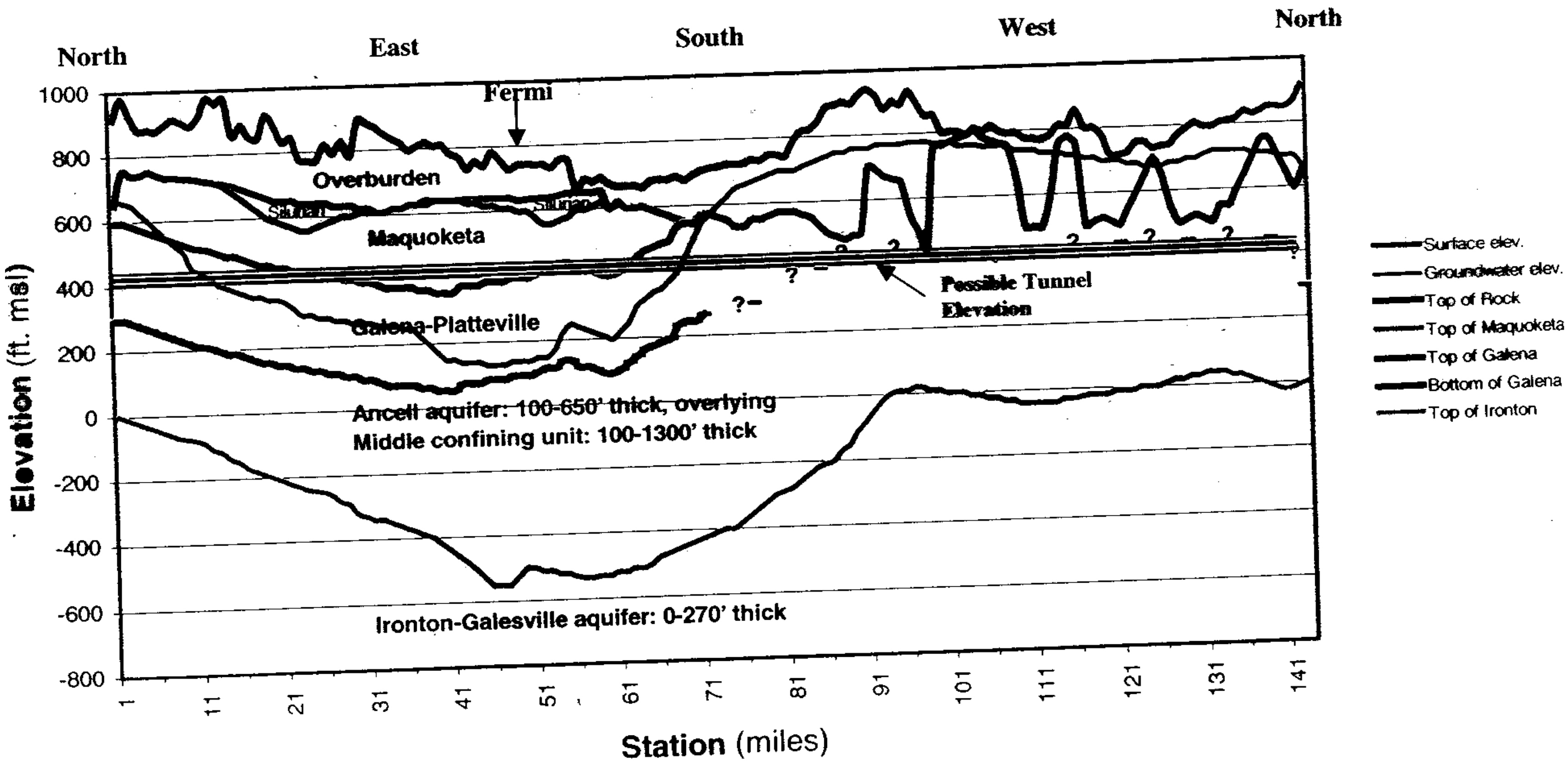

FNAL On-Site Tunnel Layouts (Transverse Scale Magnified)
Beam Stop (both dirs)
Ab
Tevatron
Clockwise Injection Line
Bonnie
Clyde
Low Field Bypass
Counter Clockwise Injection Line
Z (m)
X (m)
File: Bypass

Figure 16: Generalized Geologic Section

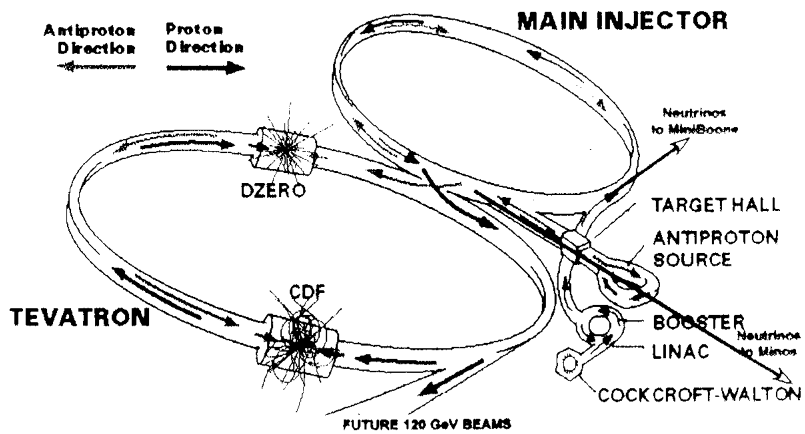
228 km Ring

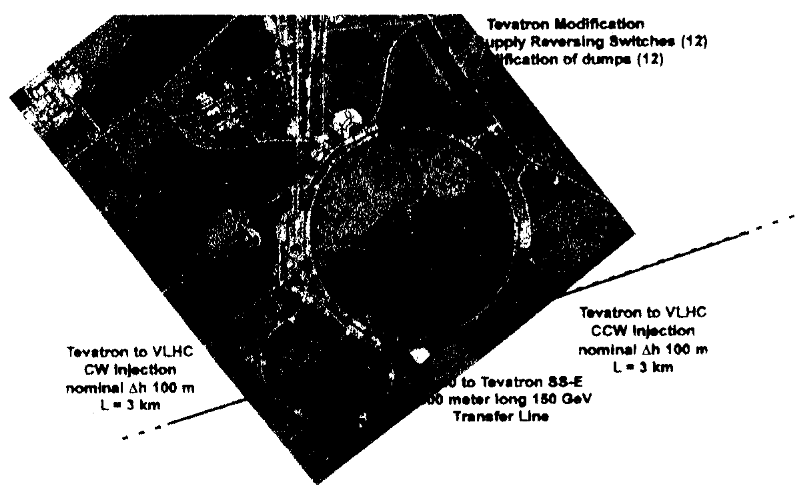
NW of Fermi

- Lampshade



Low field proton colliders





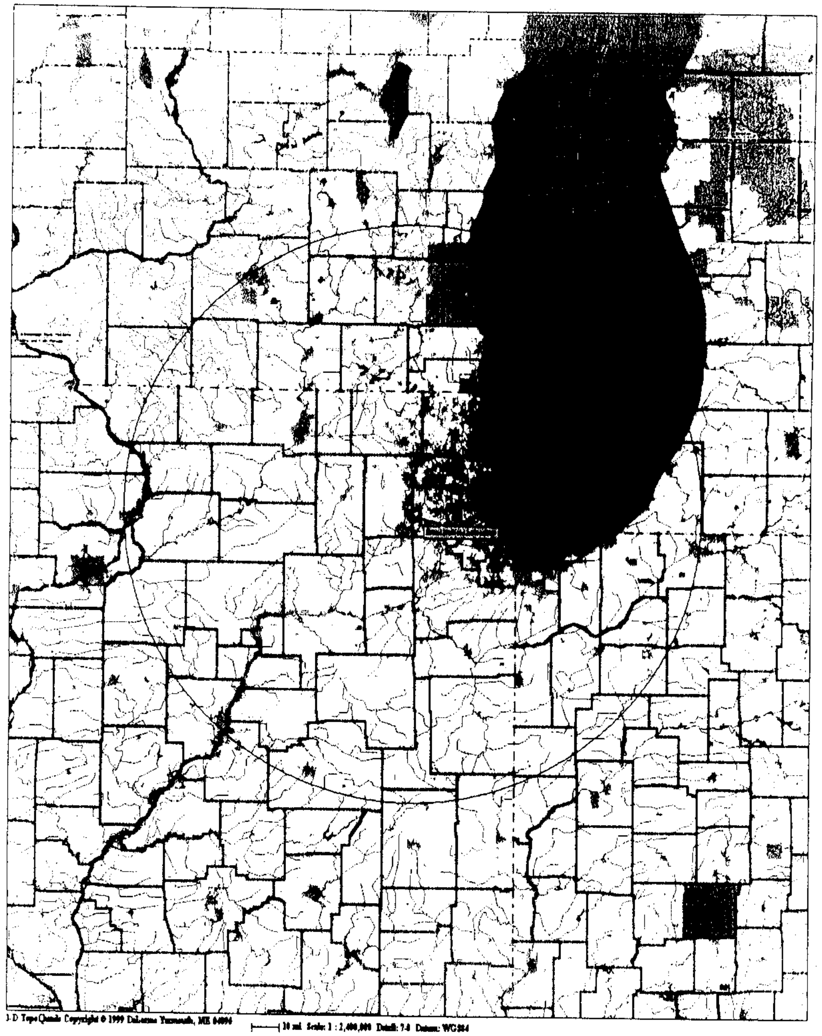
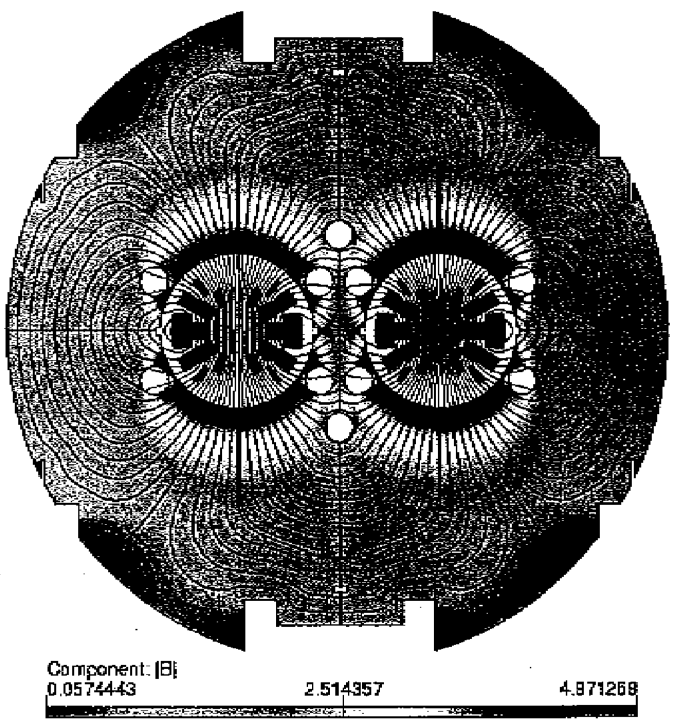
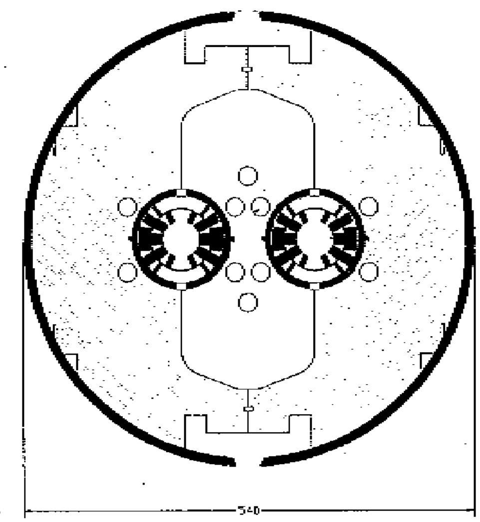


Figure 1: VLHC Maximum Study Region

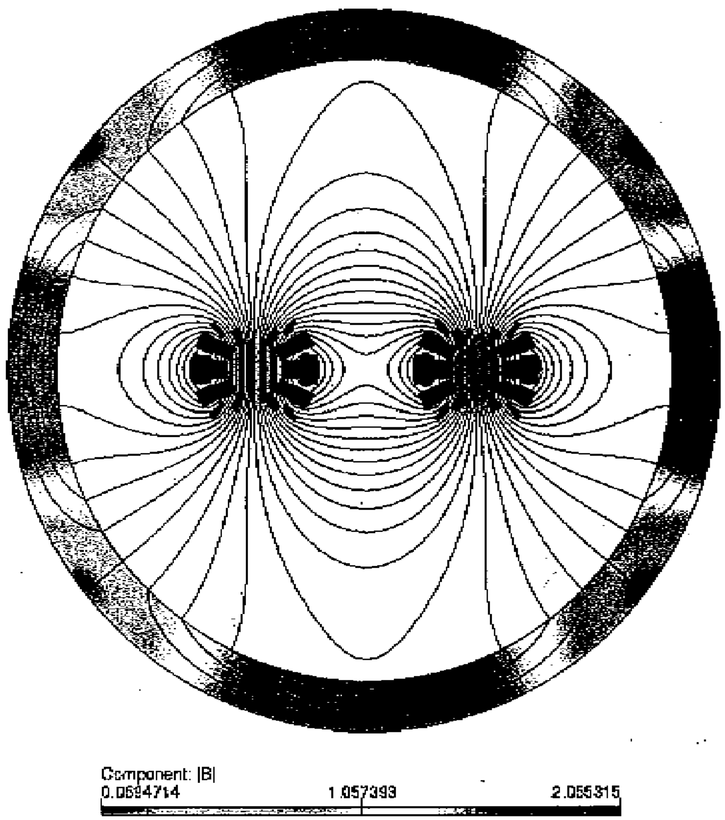
Double-Bore Cold-Yoke Design

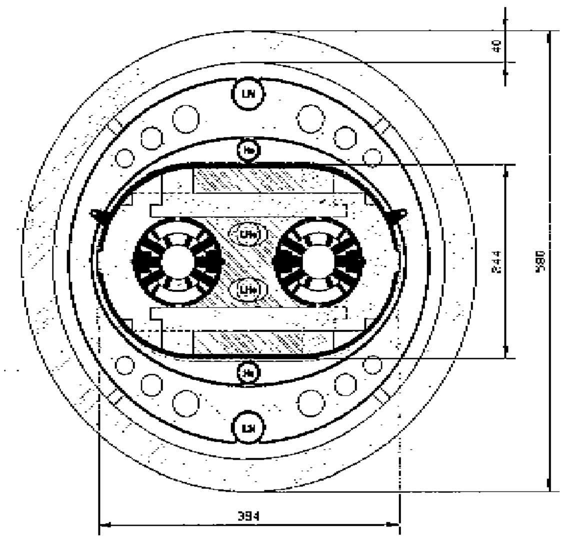




- ❖- bore diameter 43.5 mm (same coil block)
- ❖- bore separation 180 mm
- ❖- 3 piece cold yoke with vertical gap
- ❖- yoke OD 520 mm ⇨ cryostat OD ~0.8-0.9 m
- ❖- 10 mm thick SS skin
- ❖- correction holes, gap along flux lines

Double-Bore Warm-Yoke Design





- bore diameter 43.5 mm
- bore separation 180 mm
- cold mass size 385 mm
- thin SS skin
- yoke OD 580 mm = cryostat OD
- yoke thickness 40 mm
- asymmetric coils

What are the Limits?

- **The highest energy is limited by various factors:**
  - Stability issues related to ring size, impedence, ground motion, etc.
  - Magnetic field might be a limit for small rings
  - Stored beam energy is a safety problem
- **The first limit is probably synchrotron radiation (or perhaps multiple interactions per beam crossing)**
  - SynchRad puts power into the beam tube that must be removed
  - At high enough x-ray energy, it scatters directly into the magnet
  - It creates vacuum problems
- **Synchrotron radiation also has good features**
  - It damps the beam emittance, creating smaller spots, requiring fewer particles for a given luminosity