High Energy Colliders

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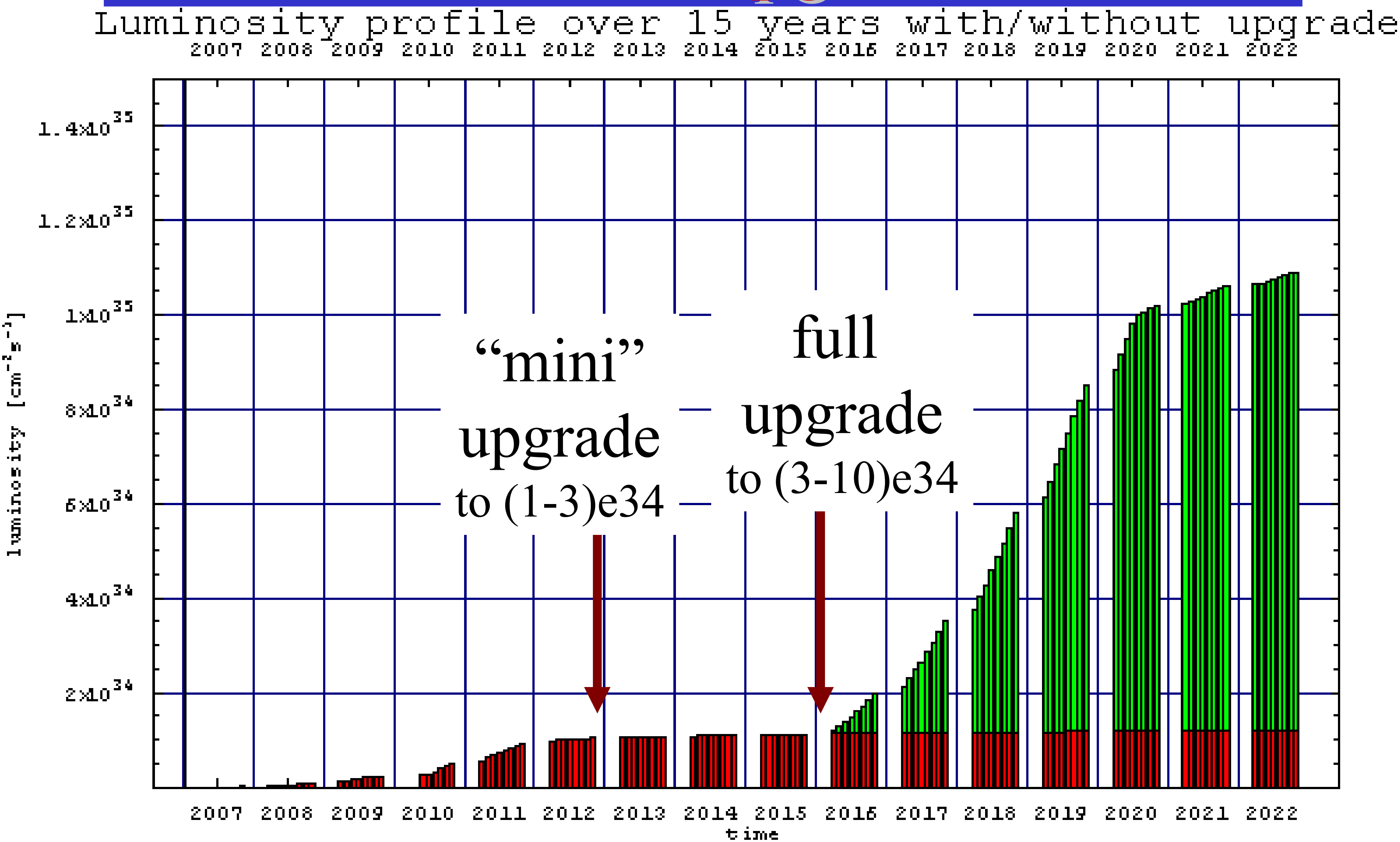
Frontier Colliders on the Table

- ILC
  - I am not gonna talk about it
- CLIC
  - I am not gonna talk about it
- DLHC
  - 4 slides
- Muon Collider
  - 1 slide; S.Geer talked about it last Monday
- VLHC
  - many slides

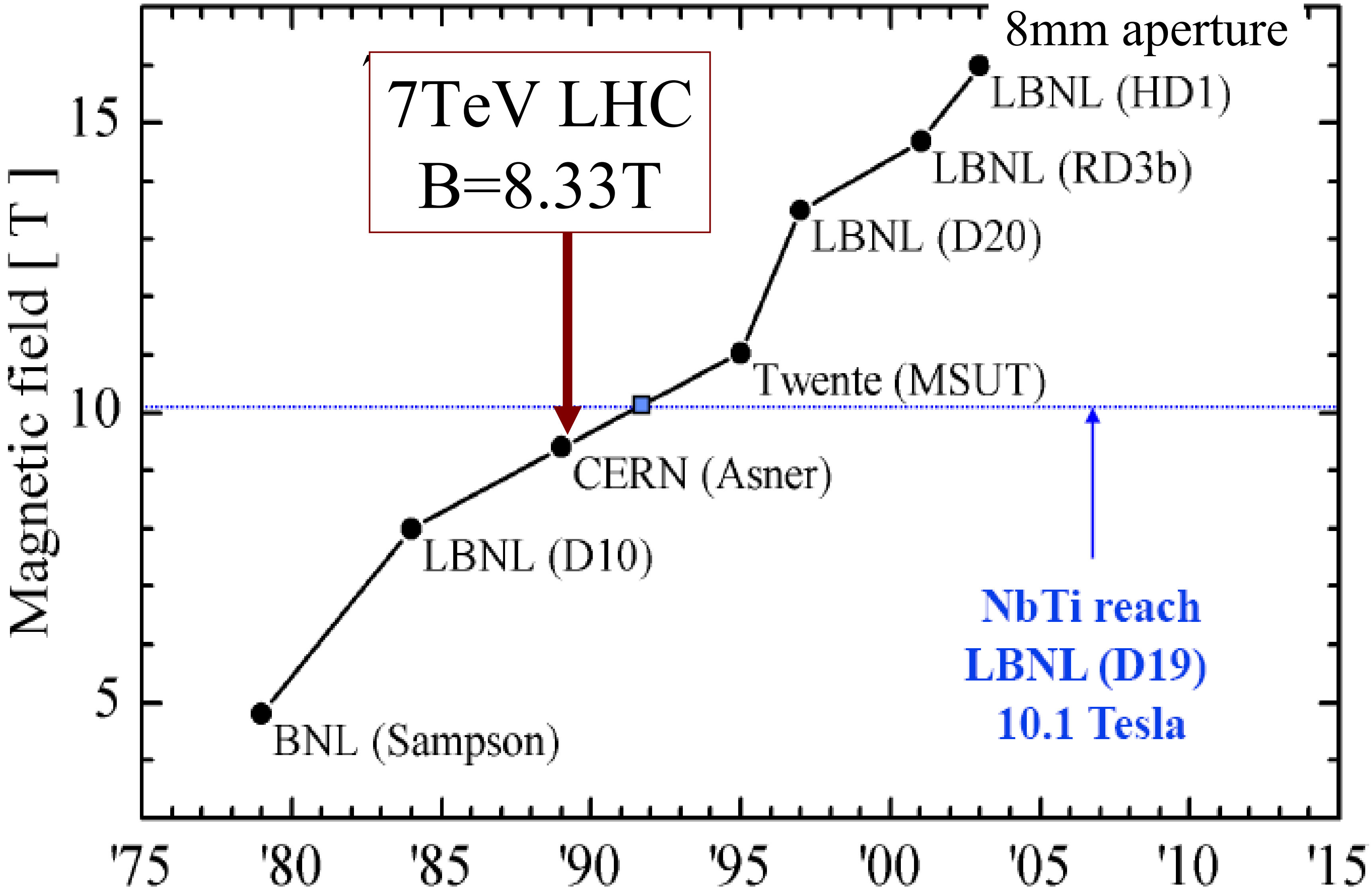
- Synopsis table at the end
  - no conclusions offered

LHC/LHC *L*-Upgrade Schedule



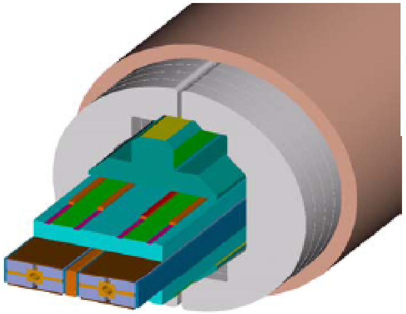
Preliminary planning studies, J-P Koutchouk

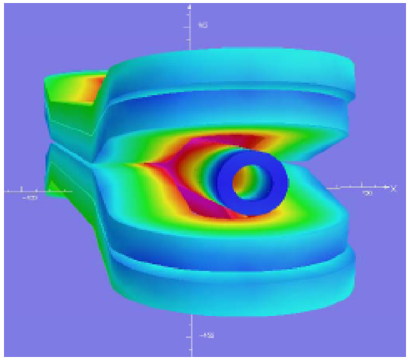
SC Dipoles for Accelerators



DLHC= 2 x LHC=17T Dipoles

LHC Energy Upgrade

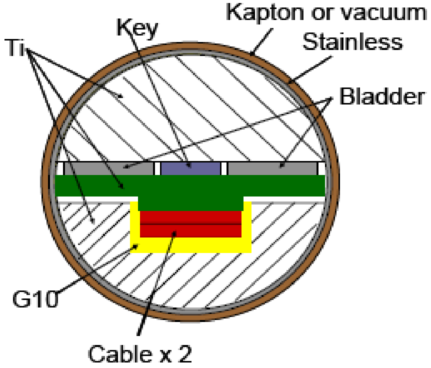




Design Features & Applications

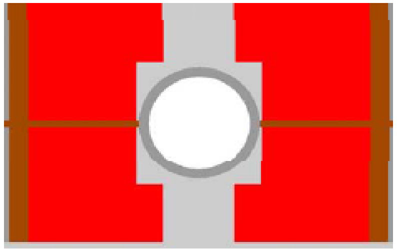
- Target field 15 Tesla
- Clear bore 36 mm
- Simple coil configuration
- Designed for high field quality
- Suitable for HF cable testing
- Compatible with HTS inserts

High-field cable testing



4.5 K Short Sample Parameters

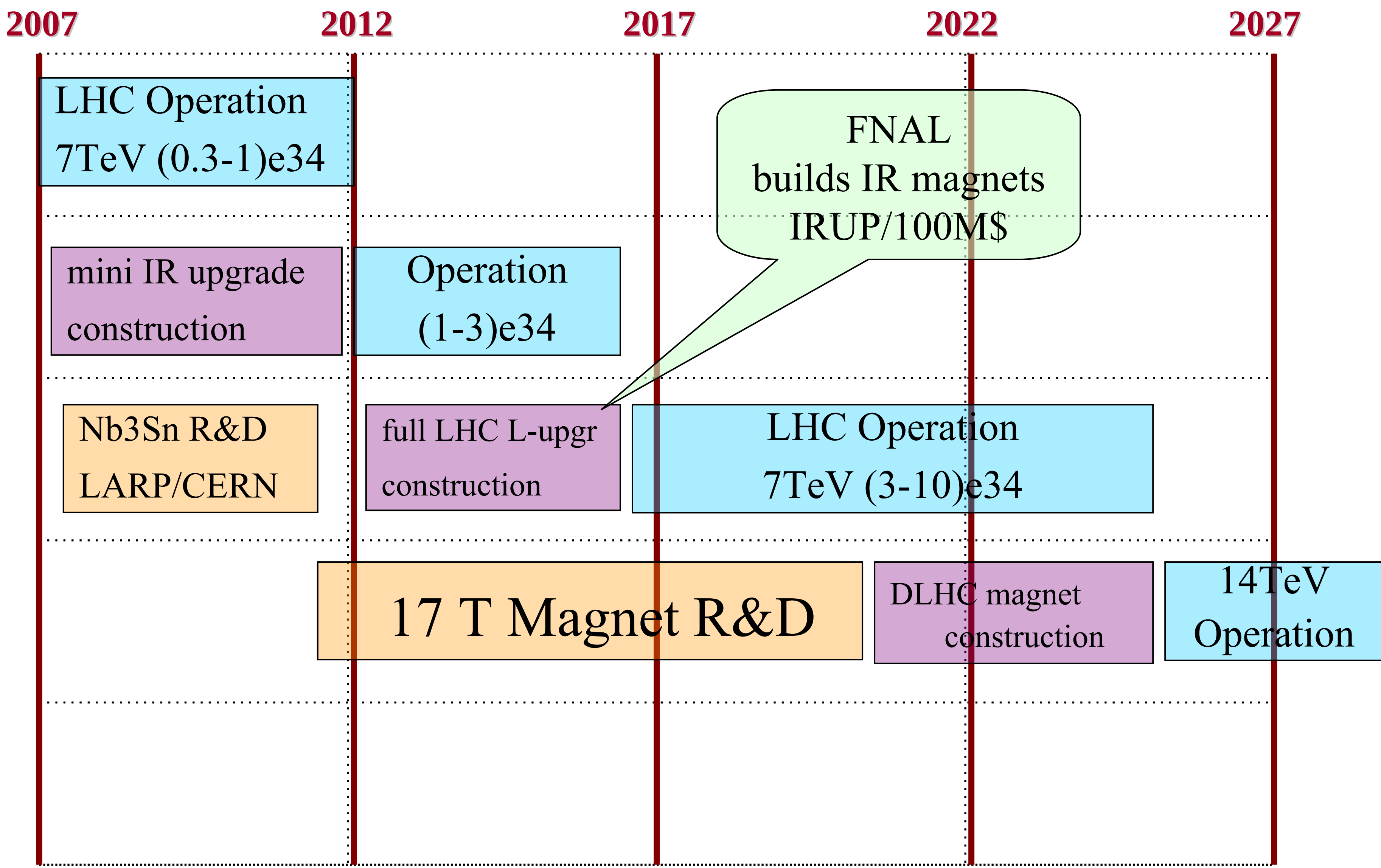
Parameter	Unit	HD1	**HD2**
Clear bore	mm	8	**36**
Coil field	Tesla	16.1	**15.8**
Bore field	Tesla	16.7	**15.0**
Max current	kA	11.4	**17.3**
Stored Energy	MJ/m	0.66	**0.84**
F_x (quadrant, 1ap)	MN/m	4.7	**5.6**
F_y (quadrant, 1ap)	MN/m	-1.5	**-2.6**
Ave. stress (h)	MPa	150	**150**



2-layer winding without spacers in body or ends

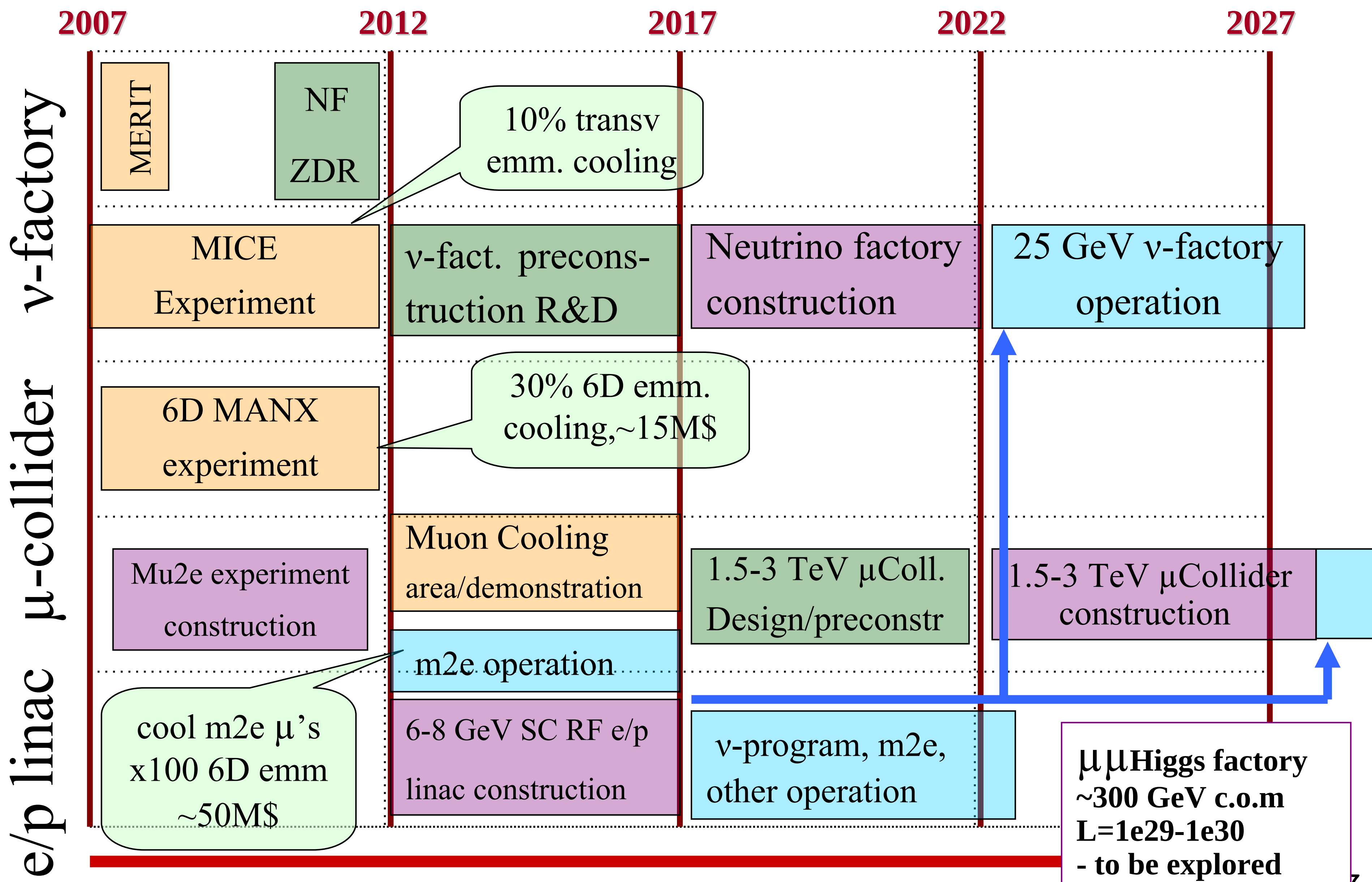
- 17 T will require new conductor, Nb3Sn
- Long way to the accelerator quality magnets:
  - 10+ years of research and development
- R&D has not started yet (LBL at the very beginning)
- …then, several (5-7 yrs) of construction and installation…

LHC, LHC+,DHLC possible map



Muon Complex Vision

VS, SG, AT



Very Large Hadron Collider

www.vlhc.org

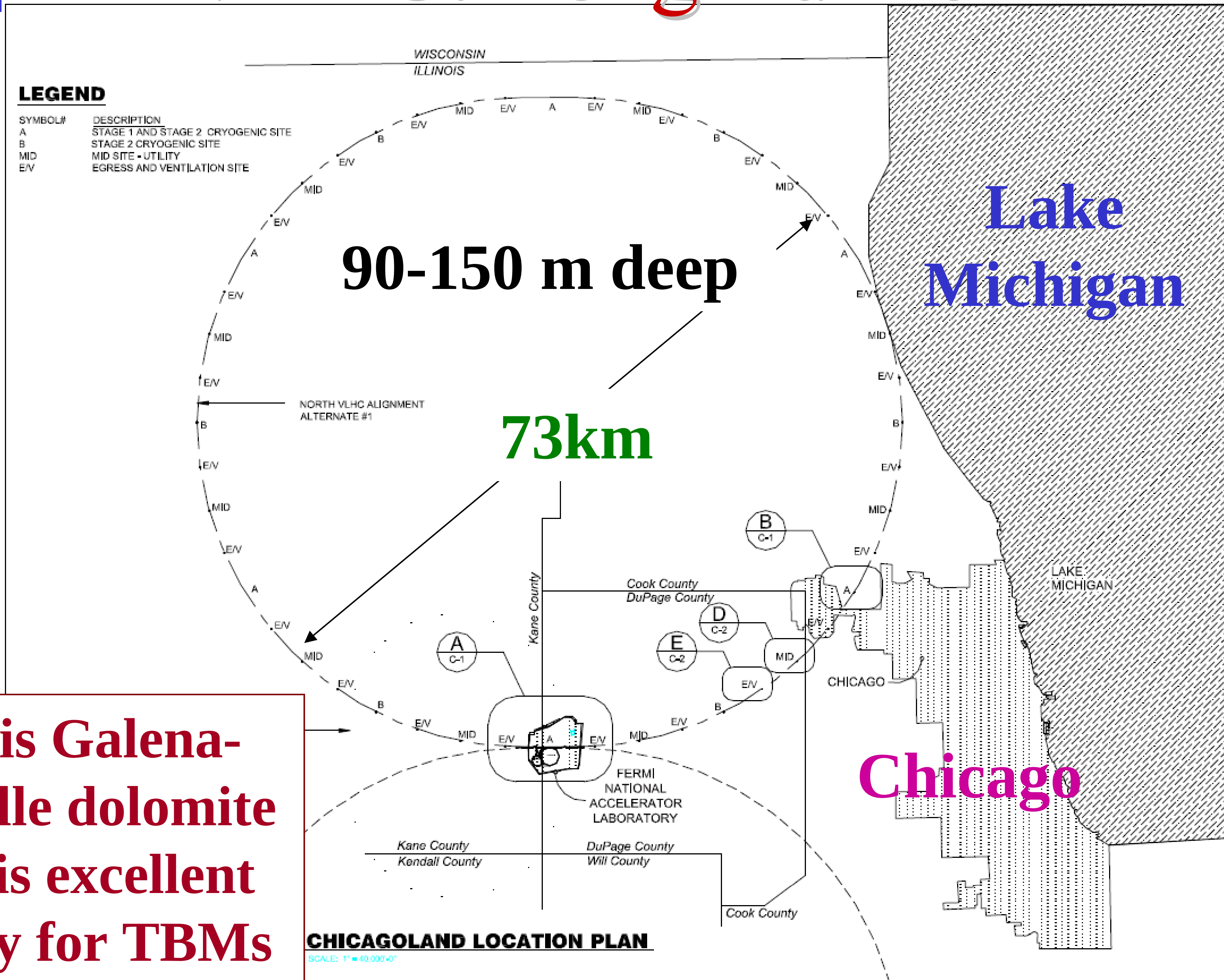
FNAL-TM-2149
(2001)

Design Study for a Staged Very Large Hadron Collider

The Staged VLHC Concept

- Take advantage of space and excellent IL geology
  - **Build a BIG tunnel (will be >50% cost of Stage I)**
  - **Fill it with cheap and robust magnets=40 TeV collider.**
  - **Later, upgrade to a 200 TeV collider in the same tunnel.**
- There are no serious technical obstacles to the Stage-1 VLHC at 40 TeV and 10^{34} luminosity.
  - FNAL injector chain : MI + Tevatron
  - low operating cost (20 MW frige power, like Tevatron)
  - cost savings can be gained through underground construction
- Stage 2 VLHC is, technically, completely feasible
  - vigorous R&D will reduce magnet cost

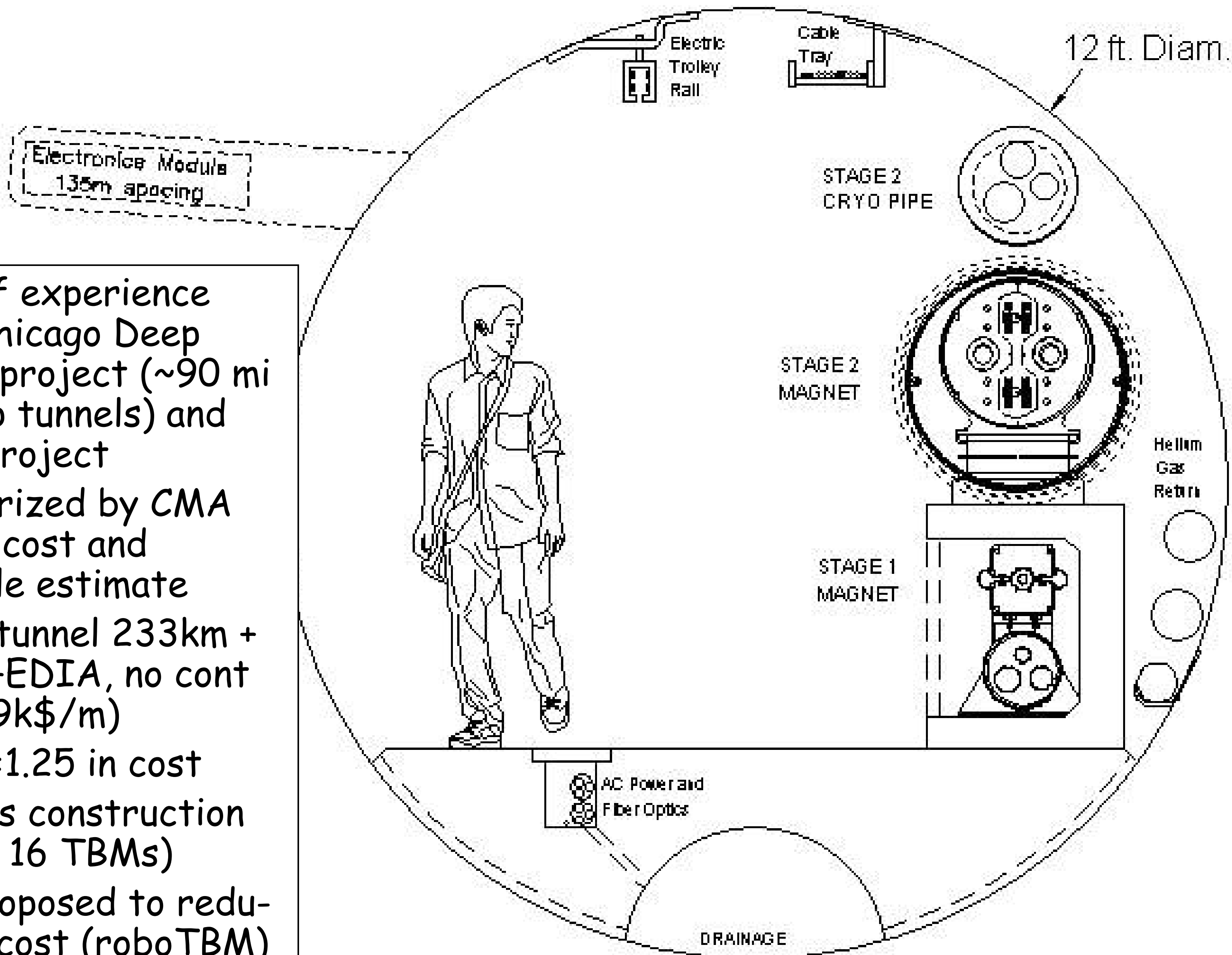
VLHC: Long Tunnel



Illinois Galena-Plattville dolomite layer is excellent geology for TBMs

VLHC Tunnel Cross Section

- A lot of experience from Chicago Deep Tunnel project (~90 mi of deep tunnels) and TARP project
- Summarized by CMA firm in cost and schedule estimate
- 12' dia tunnel 233km + shafts+EDIA, no cont =2B$ (9k$/m)
- 16'/12'=1.25 in cost
- ~60 wks construction (4m/hr 16 TBMs)
- R&D proposed to redu-ce the cost (roboTBM)



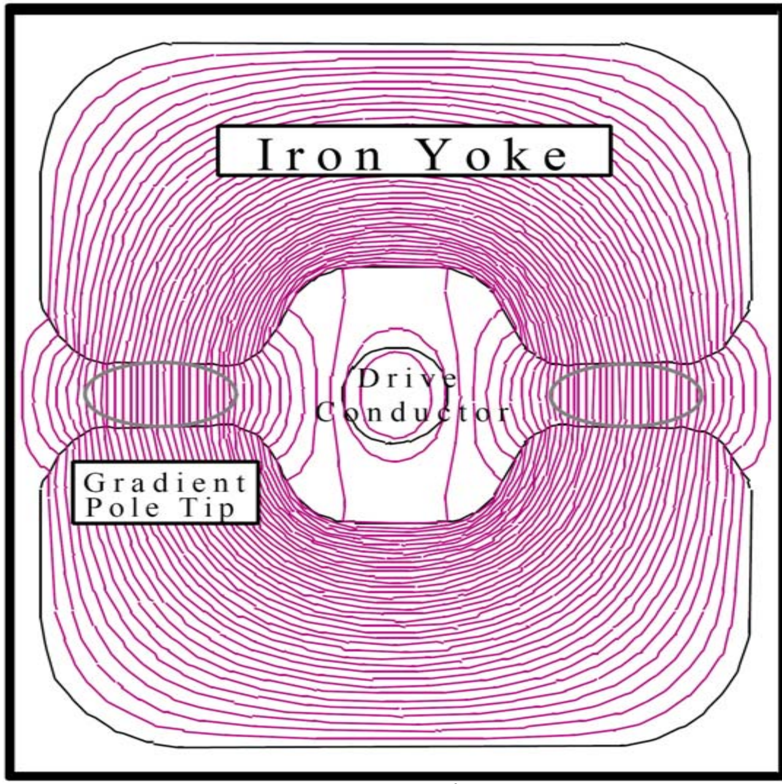
VLHC Parameters

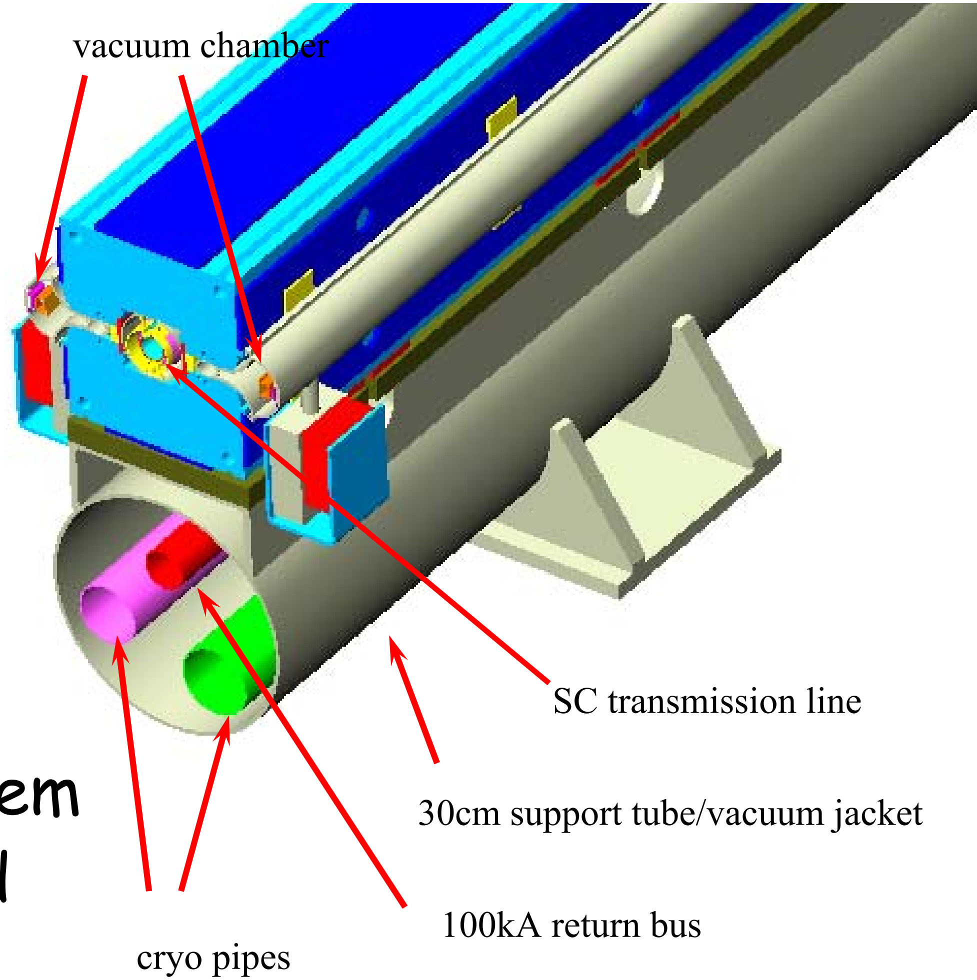
Fermilab-TM-2149 (2001)	Stage 1	Stage 2
Total Circumference (km)	233	233
Center-of-Mass Energy (TeV)	40	200
Number of interaction regions	2	2
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.0×10^{34}
Dipole field at collision energy (T)	2	11.2
Average arc bend radius (km)	35.0	35.0
Initial Number of Protons 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

What's done by 2005

- Tunnel cost and schedule exercise by CMA firm
- Transmission line design
- 100kA power supply and HTS leads built, QPS
- 104kA transmission line test in MP6
- Superferric magnets designed & optimized
- 14 m of SF magnets built and tested
- Good accelerator quality B-field measured at inj energy up to 1.96T
- Collider Phase I designed (ZDR)
- Many AP issues addressed (e.g.instabilities)
- Thorough bottoms-up cost estimate

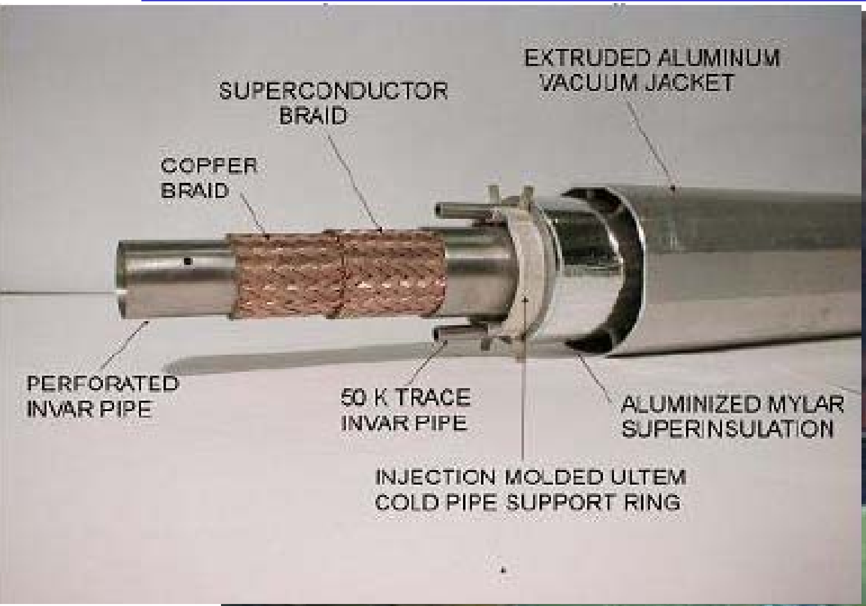
Transmission Line Magnet





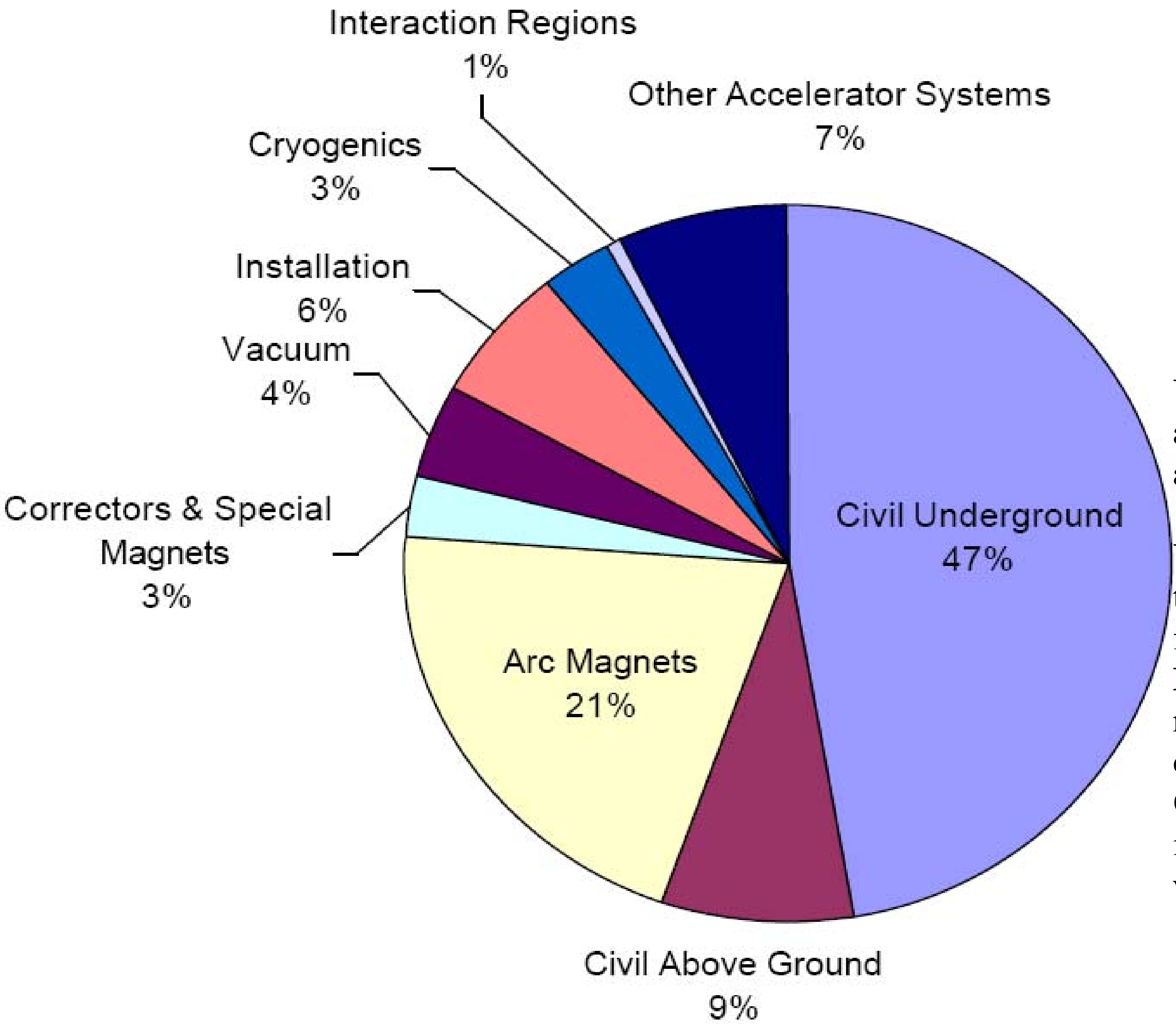
- warm iron and vacuum system
- superferric: 2T bend field
- 100kA Transmission Line
- alternating gradient (no quads)
- 65m Length

Stage-1 Magnets



100kA PS at MP6

VLHC- I: Cost Drivers



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.

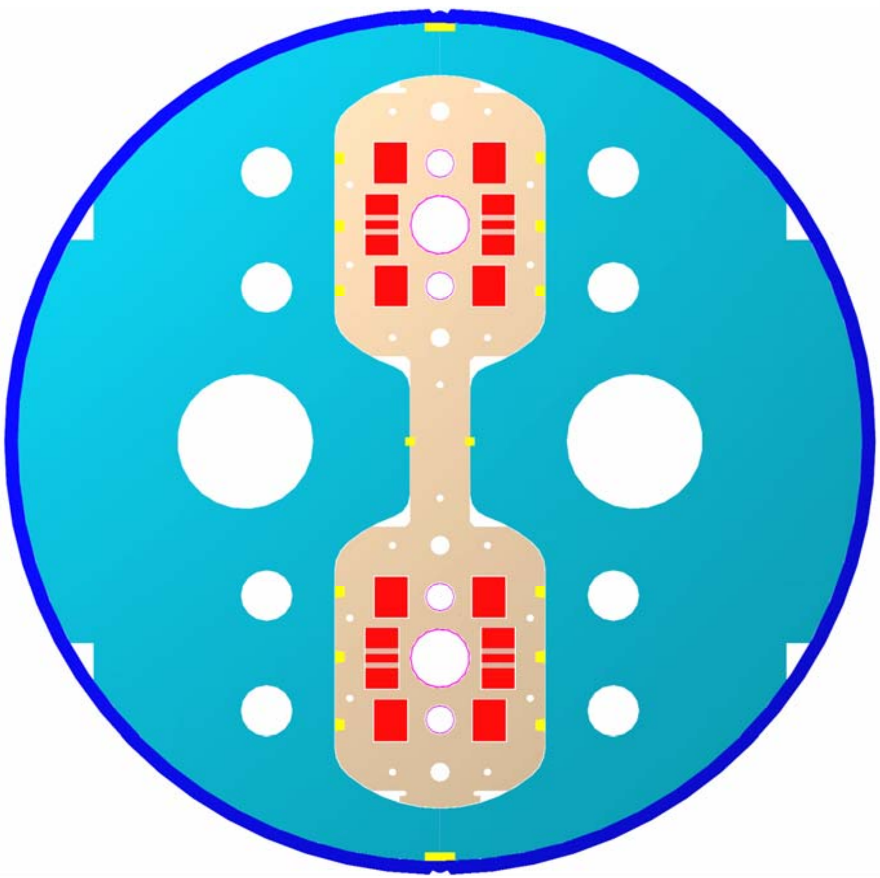
Used 2001 prices and c.a.2001 technology. No improvements in cost from R&D are assumed.

No detectors (2 halls included), no EDI, no indirects, no escalation, no contingency

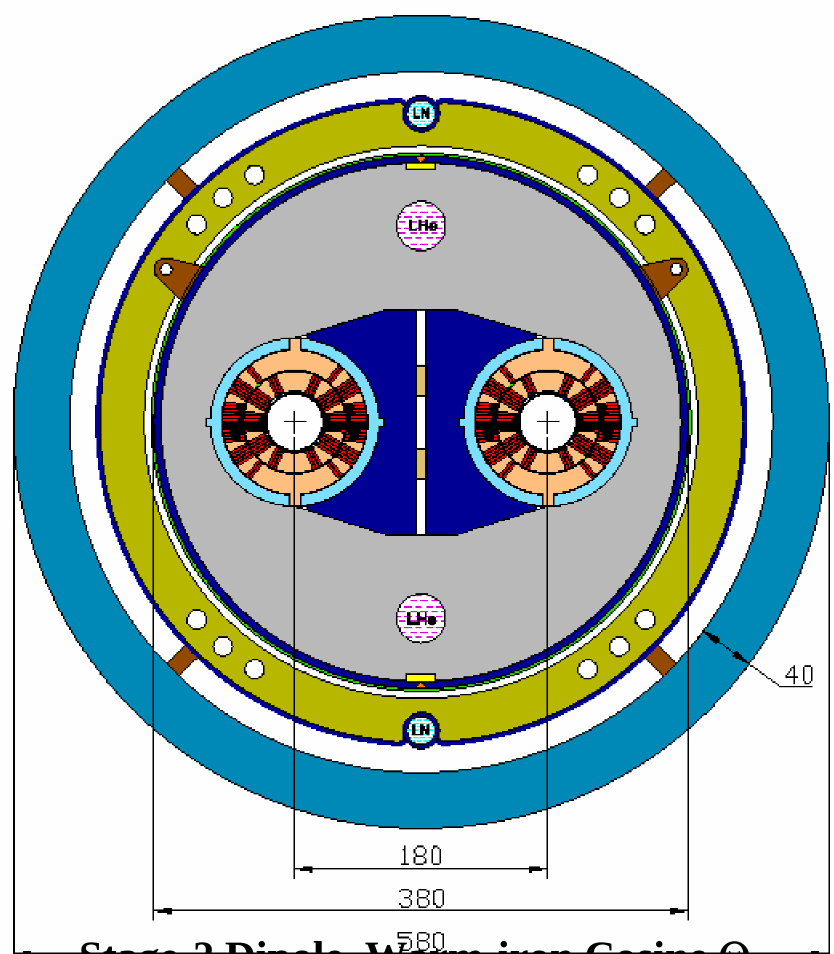
Comparison: VLHC-I construction cost is comparable to the SSC Collider Ring, which was (escalated to 2001) $3.79B

Stage-2: 10T+ Magnets

- There are several magnet options for Stage 2. Presently Nb_3Sn is the most promising superconducting material, e.g. LHC IR Upgrade magnets are being developed by US LARP



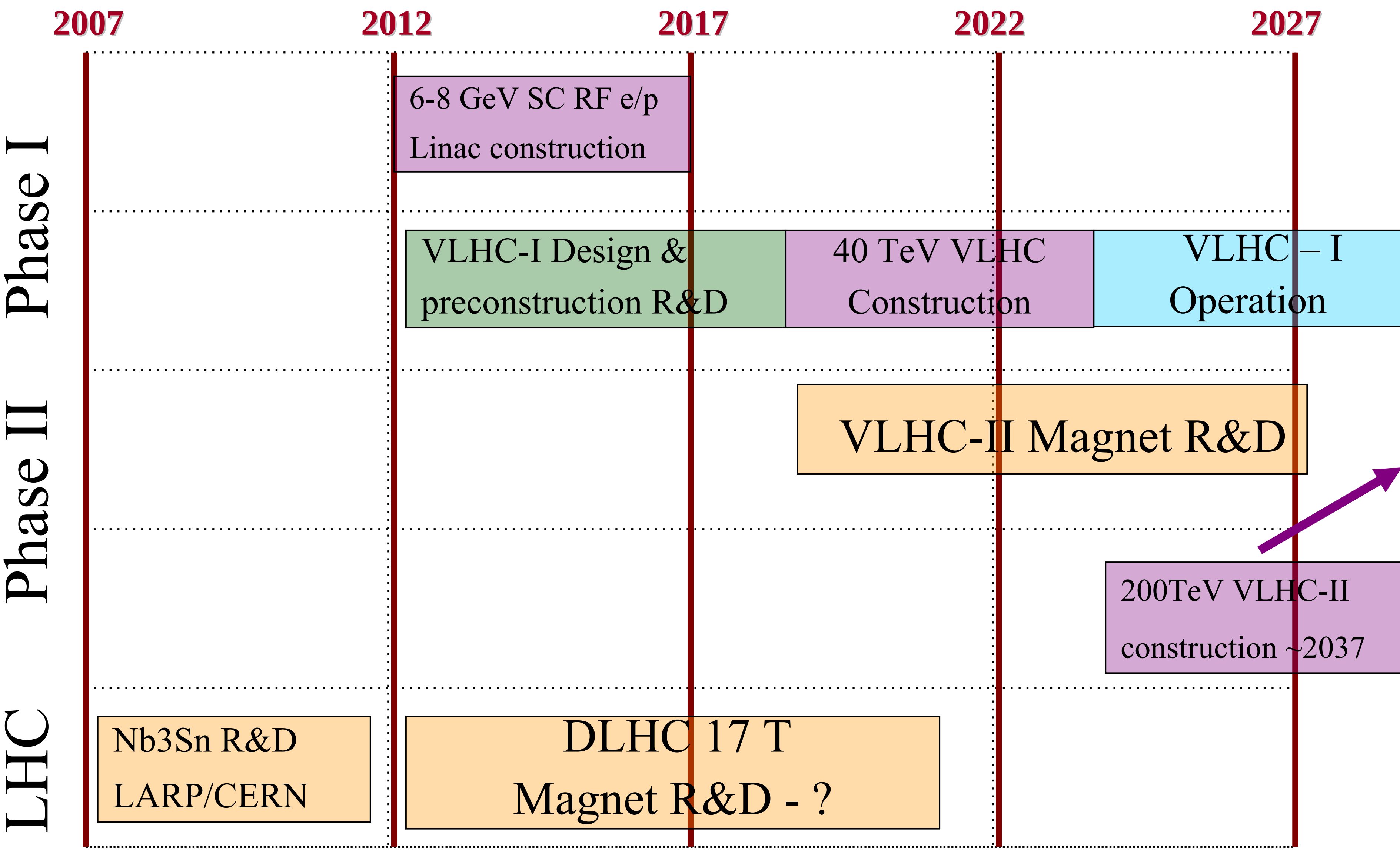
Stage-2 Dipole Single-layer common coil



Stage-2 Dipole Warm-iron Cosine Θ

VHLC roadmap

GWF, PL, VS, et al



Possibilities Considered

- 200GeV/beam VLLC (Very Large Lepton Collider) with L=8e33 in the 233 km tunnel feasible:
  - Phys. Rev. ST Accel. Beams 5, 031001 (2002)
  - m.b. even with polarization
- 15 km circumference ring fitting FNAL site as:
  - 5TeV proton injector to VLHC
  - L=5e33 46 GeV/beam Z/W factory
- 8 GeV H- linac as the 1st machine in the VLHC injector chain:
  - x3-5 smaller emittance than Booster (0.5 pi mm mrad rms norm)
  - allows proportional reduction of total current in beam-beam limited VLHC = easier instabilities, energy deposition, losses, collimation

VLHC Attractive Features

- VLHC is:
  - "low technology"
  - easy integration
  - easy industrialization and mass production
- Based on three ~"loss-free" mechanisms:
  - Superconducting current flow
  - DC magnetization of iron
  - Recirculation of protons in guiding B-field
- VLHC is the only machine under discussion which does not throw away entire beam energy each pulse:
  - Very low AC wall power VLHC-1 0.5MW/TeV
- R&D far advanced compared to other colliders

Future Colliders: Synopsis

	DLHC	ILC	CLIC	μCollider	VLHC-I	VLHC-II
C.O.M, energy	28TeV	0.5TeV	3TeV	1-4TeV	40TeV	200TeV
wrt predecessor	2xLHC	2.5xLEP	15xLEP	20xLEP	3xLHC	14xLHC
dependence on LHC results	Yes	yes	no	no	no	no
R&D req'd	yes	yes	yes	yes	no	yes
Predecessors	LHC	none	none	none	TeV, HERA, RHIC, LHC	LHC, VLHC-I
US site	none	FNAL	none	FNAL	FNAL	FNAL
Foreign site	CERN	Japan	CERN	UK?	none	none

Back up slides

VLHC-I 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 constructi
  - 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

VLHC-II 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.

"Roadmap" Comments

If I am to summarize Steering Group discussions so far:

- there is interest in having healthy physics program all the time
  - in the nearest years it means supporting neutrino experiments and m.b. launching new ones (Kaons and muons)
- 1-2% ILC e- linac demonstration is very desirable
  - part of that linac can be used for H-/proton acceleration
    - A plan of co-operation of 5GeV e- and ~8GeV H- needed ASAP
  - besides ILC R&D, the linac can/should be used for physics program (neutrino, muons, kaons?)
- seems that at the end of the Linac construction (2017?) we might be at the branching point:
  - "high tech" (ILC, Muon Coll) vs "low tech" (VLHC)
  - to be in position to decide "intelligently" we need R&D program:
    - ILC (NML & beyond), MuonColl(6D MANX & beyond), VLHC(tunnel)