Preliminary Considerations On HTS Magnet Design for LS2

Ramesh Gupta
Superconducting Magnet Division
Brookhaven National Laboratory
Upton, NY 11973 USA

A reference to basic HTS magnet design and technology (can be reached through my webpage)
http://www.bnl.gov/magnets/Staff/Gupta/scmag-course/uspas06/RG06/rg-uspas06-lecture09.pdf

BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Design Based on the Proposed HTS Magnet Design Developed for Neutrino Facility

DRAFT – BNL Proposal to Conduct Accelerator R&D - DRAFT
for a Future U.S. Neutrino Physics Program
Brookhaven National Laboratory
August XX, 2005

[Version: August 30, 2005]

Executive Summary

This is a proposal submitted by Brookhaven National Laboratory (BNL) to the U.S. Department of Energy (DOE), Office of High Energy Physics (OHEP), to conduct ***Accelerator R&D*** focused on the improvement of accelerator systems and capabilities needed for effective realization of future accelerator-based sources of ***intense neutrino beams***. Our proposal emphasizes the most pressing R&D needs required by the ***'Super Neutrino Beam'*** concept identified in the 2004 Office of Science Future Facilities Intiative[1]. The proposed R&D work will be central to the future effectiveness of the U.S. Neutrino Oscillations Program using accelerator sources of neutrinos. We outline a program that is structured to evolve over a three-year period, indicating technical goals, requested OHEP support levels and staffing levels to meet these national objectives. The proposed R&D topics are described in detail in the Main Text sections below. A prioritized list of topics and proposed support levels is provided here.

Our 1st priority is directed to generic high-power, proton target and integrated target/horn meson-focusing systems R&D. This proposed R&D work will be needed by *any accelerator source* that proposes to advance the capabilities of the U.S. in future accelerator-based neutrino experiments. We also observe that, beyond the neutrino-less double beta-decay and high-precision reactor neutrino experiments currently under consideration for near-term approval, the future effectiveness of neutrino oscillation research will depend upon the development of Megawatt-class target sources and Megaton-class detectors, hence the need for the high power proton target and horn R&D. Our 2nd R&D priority is for development of proton beam transport magnets using high temperature superconductors, a development that will significantly reduce electrical power costs during the operations period of a super neutrino beam program. Our 3rd priority is for the development of novel, Fixed-Field, Alternating-Gradient (FFAG) conceptual accelerator designs that could provide a less costly, high-power proton driver for neutrinos than the present superconducting linac approach. The potential applications of a successful FFAG R&D program extend beyond the improvement of future neutrino beam facilities into the regime of general application to new, high-power proton accelerators for a variety of new scientific applications.

Although there were other quite compelling R&D projects and tasks that we considered adding to this proposal, we felt that the program presented here needed to be held to the requested funding levels. We felt that this dollar level could be supported by DOE OHEP, even under very stringent budgets.

We supply here, a Table of proposed Accelerator R&D projects listed in BNL's priority order.

Table of BNL Accelerator R&D Topics and Budgets by Fiscal Year

Project Name	BNL Priority	FY06 ($K)	FY07 ($K)	FY08 ($K)	Total ($K)
Target Materials & Target/Horn Integration	1	820	970	290	2080
High Temperature Superconducting Magnets	2	363	321	0	684
FFAG Accelerators For Neutrino Physics	3	351	487	385	1223

We will seek an opportunity to discuss these ideas with DOE-OHEP at a meeting to be scheduled in Germantown in the near future.

[1] "Facilities for the Future of Science, A Twenty-Year Outlook", U.S. DOE Office of Science, Nov 2003.

<u>2.0 High Temperature Superconducting Magnets:</u> R. Gupta, PI

<u>High Temperature Superconducting Magnet R&D for Neutrino Physics Application</u>

Continued magnet R&D on cryogen-free super-ferric magnets (Fig. 1) based on High Temperature Superconductors (HTS) is proposed as a way to significantly reduce the operating cost and also potentially reduce the construction costs of the future Super Neutrino Beam Facility identified as part of the DOE Office of Science's 2003 Future Facilities Plan. The present proposal is built upon the recent success of the proof-of-principle HTS magnetic mirror model developed at BNL as part of the Rare Isotope Accelerator (RIA) R&D program [1]. Design concepts are being further developed so that these magnets, fabricated using commercially available HTS tape, become comparable in cost to room temperature water-cooled copper magnets requiring a field over 1.5 Tesla. Moreover, since HTS dipoles can generate significantly higher fields (~2.5T) than room temperature dipoles, this approach would also improve the technical performance of the targeting system, resulting in a more compact primary proton beam transfer line, thereby allowing a longer decay length and/or a shorter, cheaper tunnel.

A primary proton beam transport constructed from such HTS magnets, operating at a temperature of ~35K, will be much more compact than room temperature magnets and will be cooled by plug-in cryo-coolers; hence, no cryogenic plant will be needed. HTS magnets will significantly reduce or potentially eliminate the beamline cooling water system. The magnets will operate below 300 amps, a factor of ten lower than the current required for room temperature magnets. The development of these magnets would not only reduce the operating cost (and perhaps overall construction cost) of the Super Neutrino Beam,

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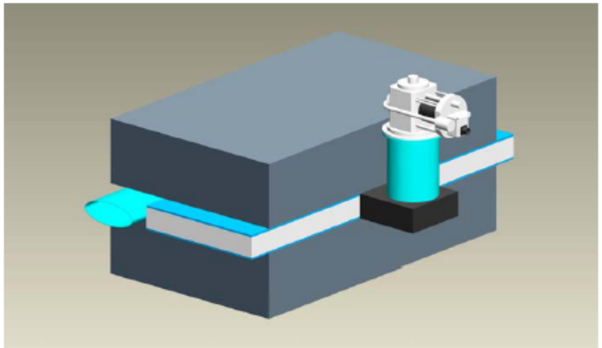
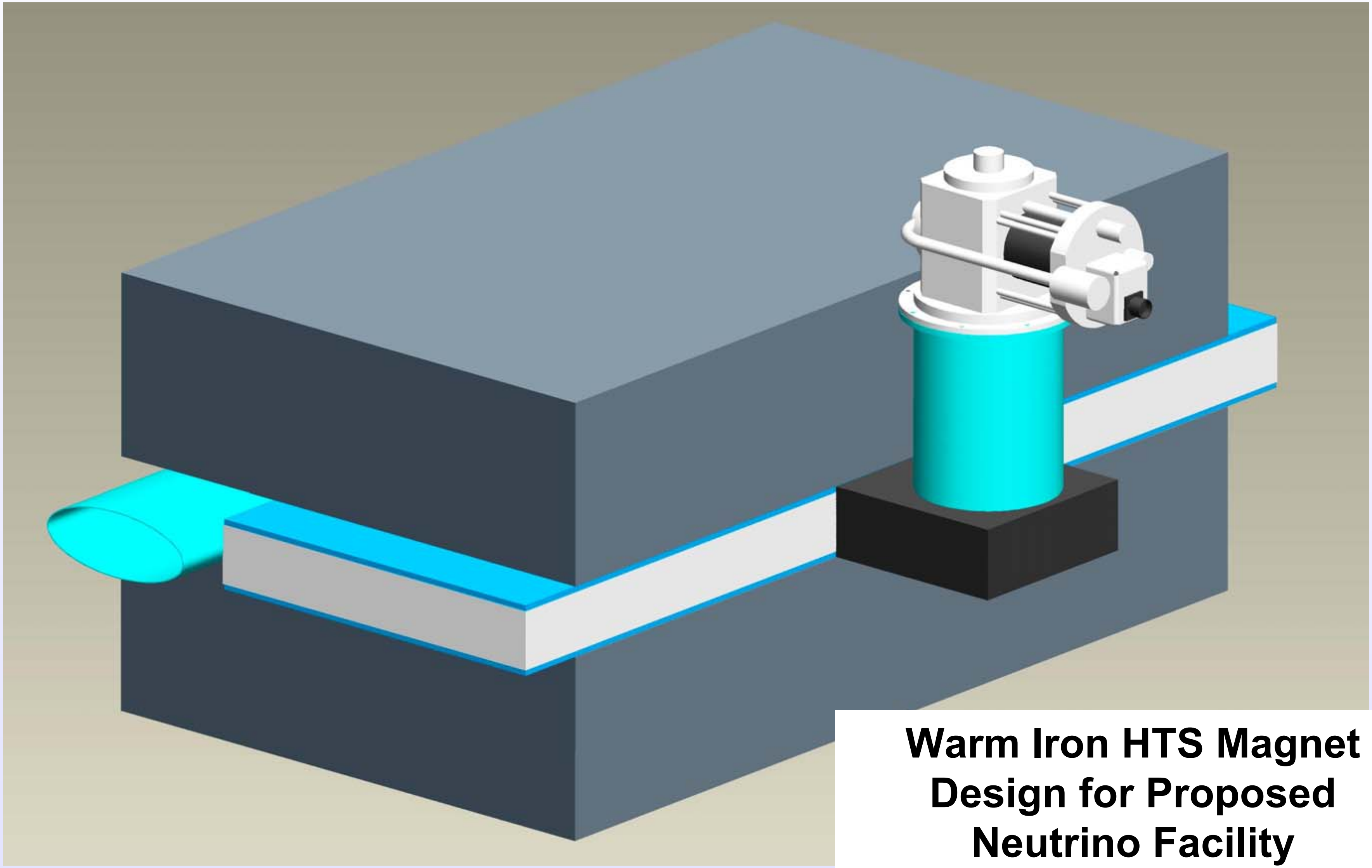


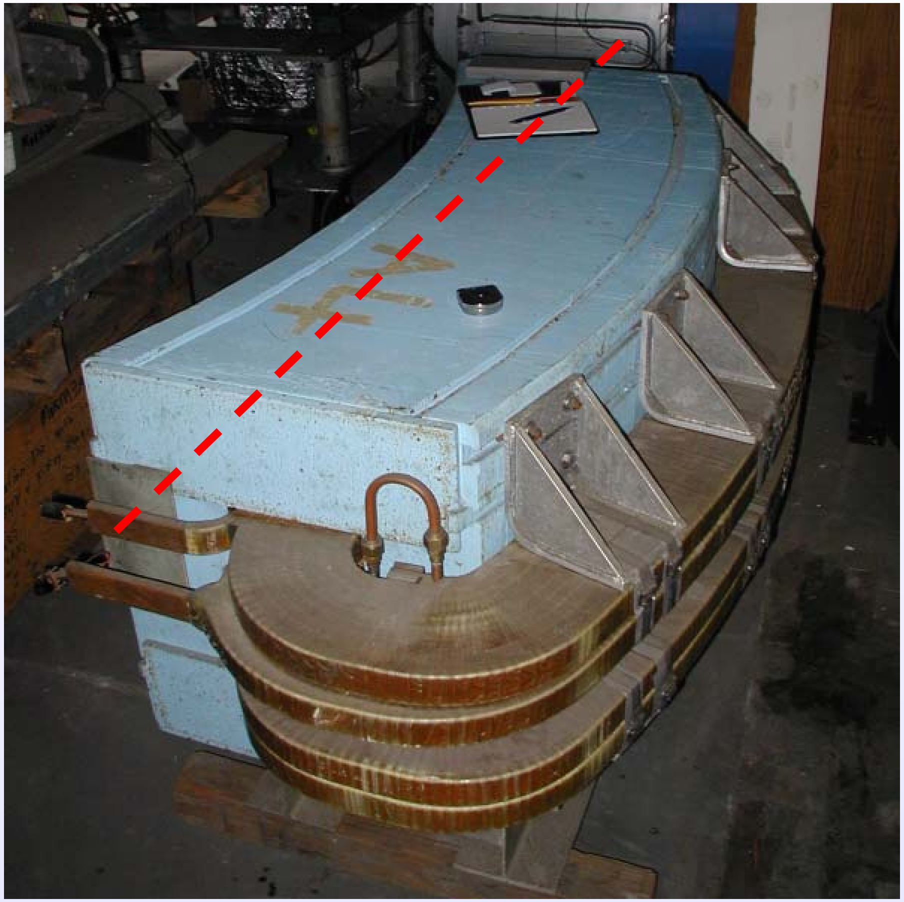
Fig. 1: *Conceptual design of HTS magnet with cryo-cooler for Super Neutrino Beam Line at AGS*

Magnet Concept with Cryo-cooler



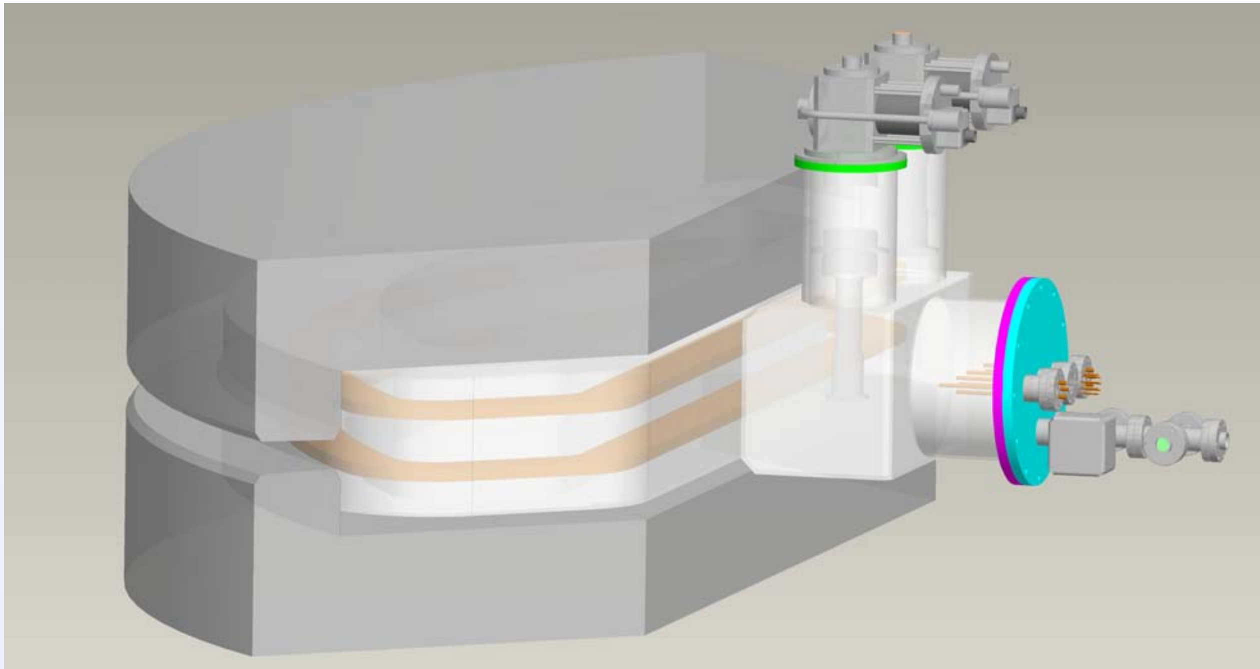
Warm Iron HTS Magnet Design for Proposed Neutrino Facility

Pictures of VUV Ring Magnet with Sagitta (Note: Coil has a reverse bend on one side)



In the proposed design the HTS coil will go on the outer lag (return yoke). One side of the coil will be curved and other side will be straight and thus the problem of negative curvature (sagitta) will be avoided.

A Proposed Way to Build Dipoles Having Large Sagitta With Brittle Superconductors

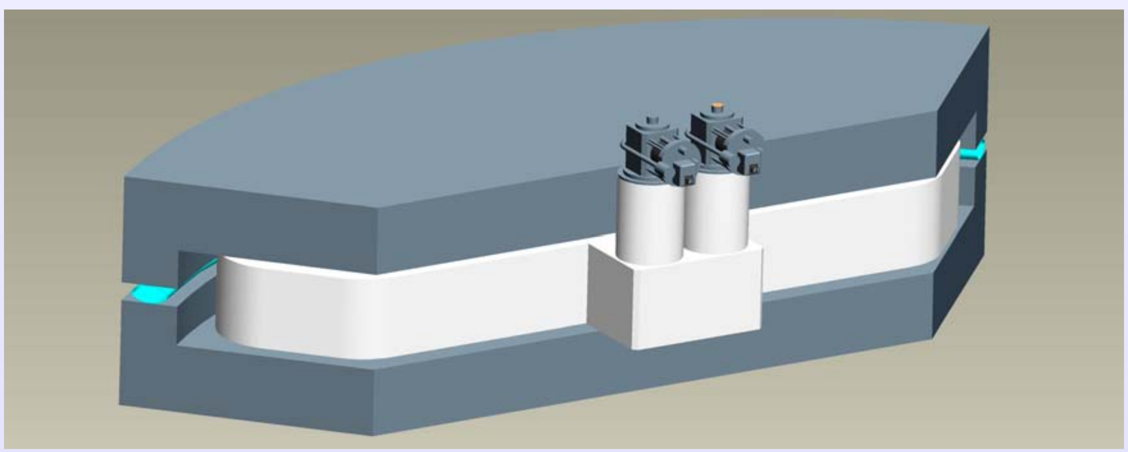


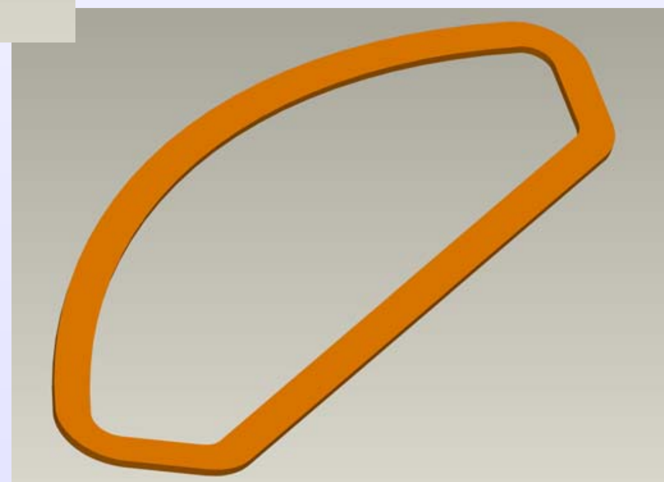
Note: The coils do not need a reverse bend.

Clear pole gap is where the electromagnetic radiation come out.

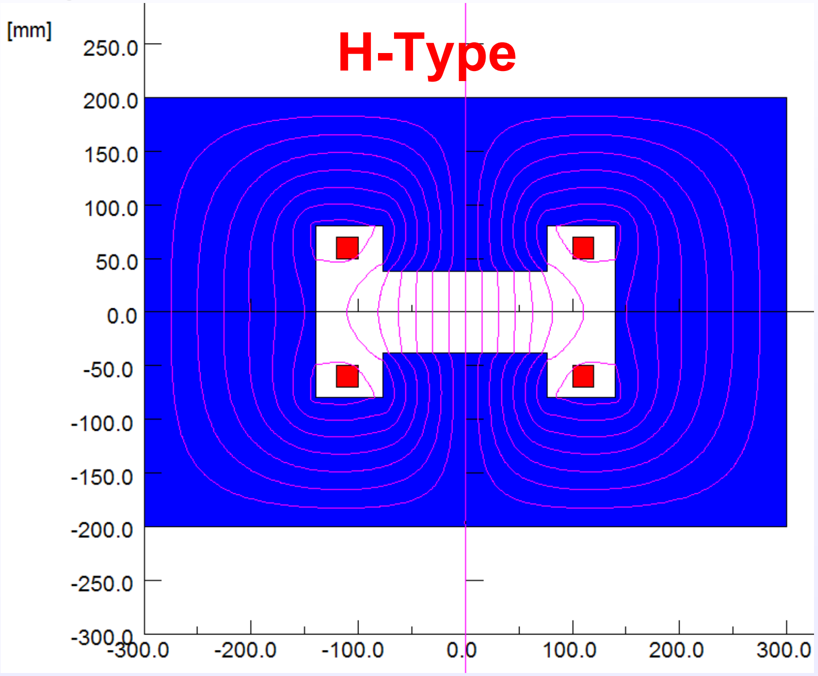
Concept simulated for VUV dipole geometry

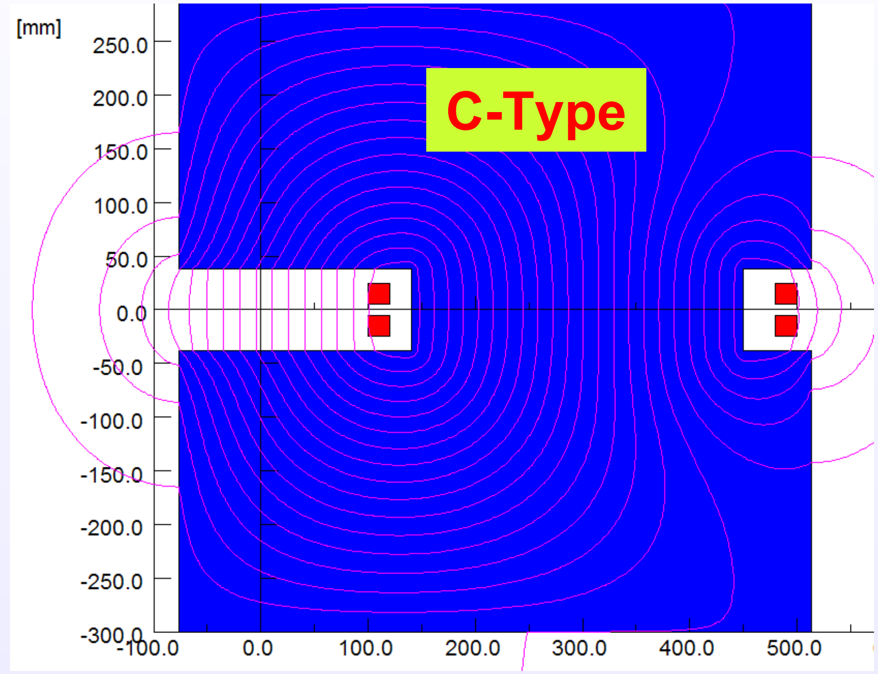
(Sketches by Paul Kovach)





Two Types of Basic Designs





We prefer C-type over H-type. It should produce lower cost HTS magnets

(a) Needs one cryostat instead of two

(b) Simpler and cheaper support structure because no need to deal with vertical forces

(c) Heat leaks will be lower

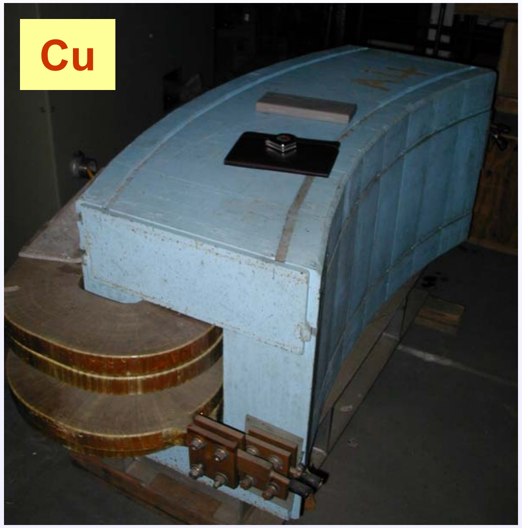
(d) Need much less superconductor because field is parallel to superconductor surface

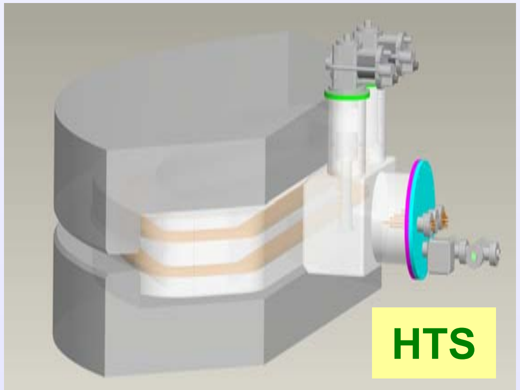
(e) Need for reverse bend in coil winding because of sagitta, can be eliminated

(f) Should facilitate a simpler and cheaper cryostat design

A Case Study for Cost Comparison of Copper and HTS Dipole for Neutrino Facility (This is NOT LS2)

Design Parameters:
- B = 1.55 T
- L = 3.73 m
- Pole width = 153 mm
- Pole gap = 76 mm





Copper Magnets:
- Better known costs (estimated : ~150k$ each for this magnet)
- Cost of individual components like coil, yoke, etc., is well understood
- High operating costs (estimated ~3 MW total)
- Low thermal conductivity water cooling plan
- Higher current (a few kA) power supply (higher cost)
- Maintenance issues (cost, downtime): water leak etc.

Desired cost of support structure and cryostat in this HTS magnet: < 20 K$

HTS Magnets:
- Develop designs to reduce cost (goal : ~150k$/magnet for equivalent integral field)
- Cost of HTS. present price : ~50 k$ (only 1/3, expected to go down)
- Need to include cost of other components like iron (low and well understood), support structure, cryostat (major driver unless better designs developed)
- Lower operating costs (wall power of cryo-cooler?)
- Cost of cryo-coolers (compare with infrastructure cost of Low Thermal Conductivity Power Plant)
- Lower current (a few hundred Amp) power supply (cheaper)
- Maintenance issues (cost, downtime): cryo-coolers

Some LS2 Dipole Parameters

The known parameters are :

Bending angle per dipole 5.625 degrees (pi/32),

these are parallel edge magnets

radius of trajectory 14.3 m (or longer)

Maximum magnetic field - 8.4 kGs (9 is a good round number)

Gap ~ 3 cm

Horizontal aperture - ± 3 cm

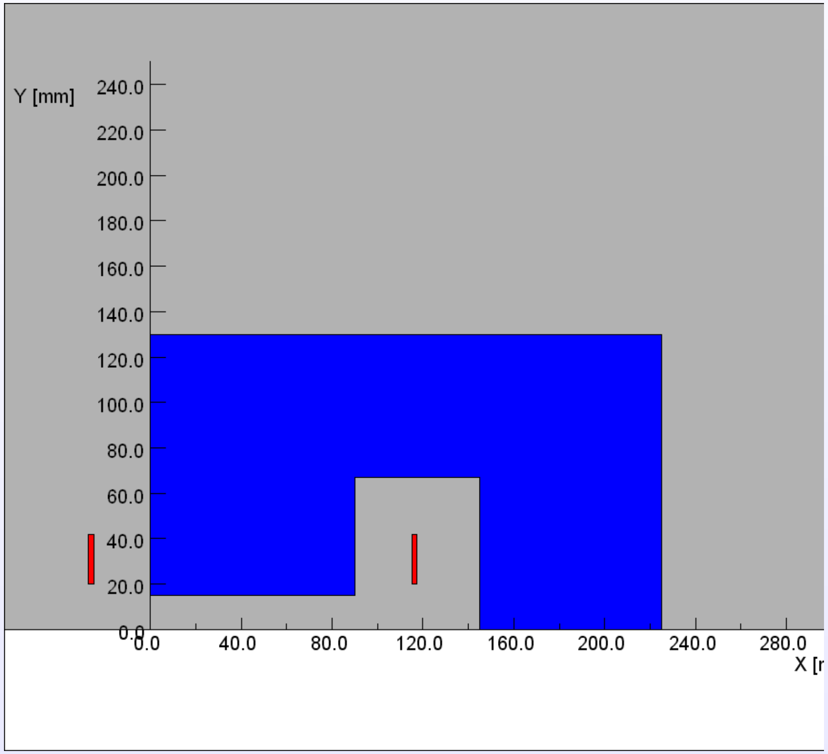
Do you need anything else to start?
Cheers,

Vladimir N. Litvinenko, Senior Physicist

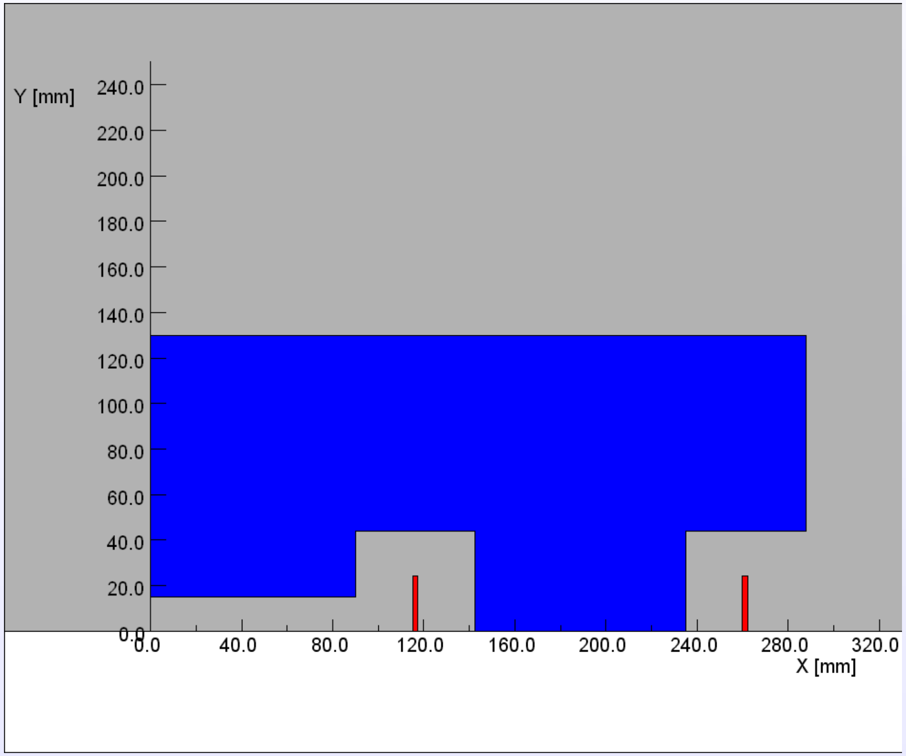
It is not known if the aperture numbers are for good field aperture or physical aperture.

Therefore, initial design is for an educated aperture.

Two Magnet Styles



Pole Powered
(earlier referred to as H magnet)



Return Leg Powered
(earlier referred to as C magnet)

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Conductor Requirements

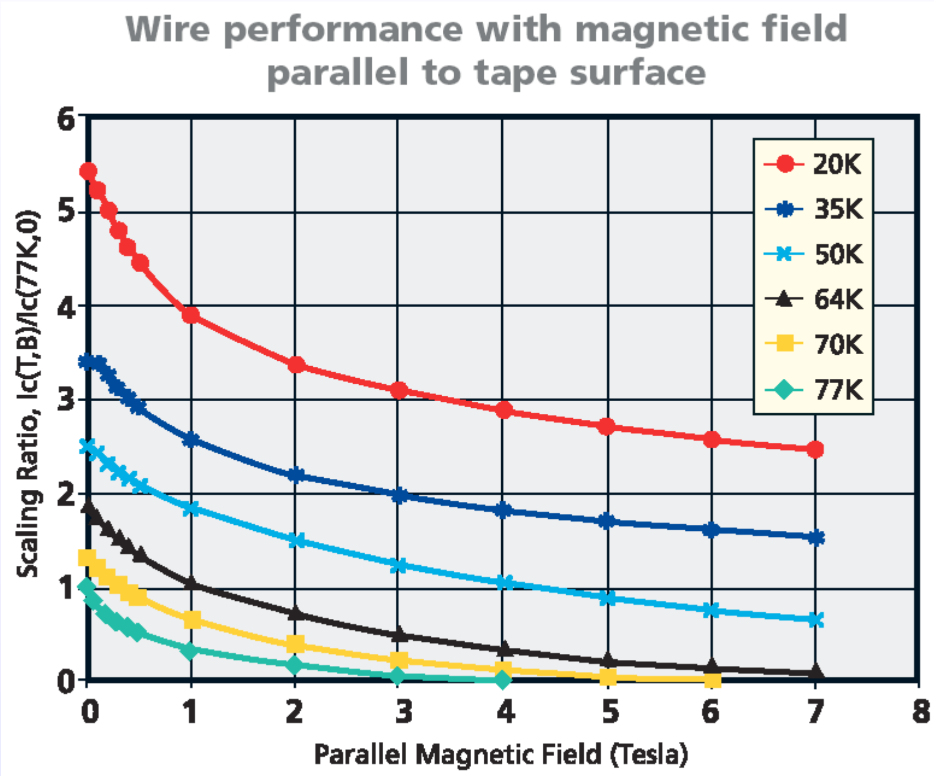
LS2 HTS dipole options - first cut for 0.9 T design
Pole gap (lower to upper) = 30 mm, pole width = 90 mm (stated horizontal aperture +/- 30 mm)

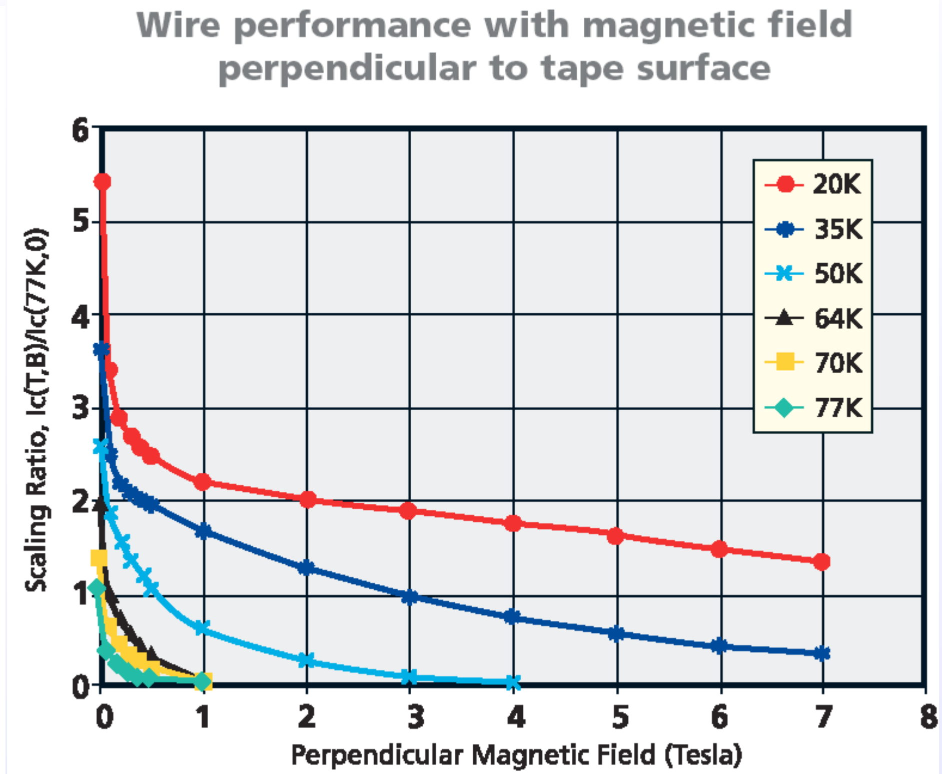
Rough conductor requirements and coil parameters
Taking design to next step requires clarification from AP regarding what 30 mm gap and +/- 30 mm horizontal aperture means

35 K operation	
Design D5 (C-type, one cryostat)	
Amp-turns/quadrant/one coil	12000
Amp-turn-m (L=1.4m, w=0.15m)	74400
Conductor Length for 125 A	595
Length for 2 scaling (35 K,0.35T)	298
Total cost for $20/m	5952
with 10% extra	$ 6,547.20
coil thickness X width (in mm)	2.5 X 48 (x2)
Design E2 (H-type, two cryostat)	
Amp-turns/quadrant/one coil	11000
Amp-turn-m (L=1.4, w=0.15)	68200
Conductor Length for 125 A	546
L for 2 scaling (35 K,0.38T)	273
Total cost for $20/m	5456
with 10% extra	6002
coil thickness X width (in mm)	2.5 X 22 (x4)

64 K operation	
Design D5 (C-type)	
Amp-turns/quadrant/one coil	12000
Amp-turn-m (L=1.4m, w=0.15m)	74400
Conductor Length for 125 A	595
L for 0.45 scaling (64 K,0.35T)	1323
Total cost for $20/m	26453
with 10% extra	$ 29,098.67
coil thickness X width (in mm)	12.5 X 48 (x2)
Design E2 (H-type)	
Amp-turns/quadrant/one coil	11000
Amp-turn-m (L=1.4m, w=0.15m)	68200
Conductor Length for 125 A	546
L for 0.42 scaling (64 K,0.38T)	1299
Total cost for $20/m	25981
with 10% extra	28579
coil thickness X width (in mm)	12.5 X 22 (x4)

Critical Current of BSCCO 2223 Tape As a Function of Field At Various Operating Temperatures





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Current carrying capacity of HTS depends on:

- **Temperature**
- **Magnitude of the field**

and also on the direction of the field

Reduction in Conductor Requirements

Following is the result of study of horizontal component of field with vertical space between top of the coil and cryostat in LS2 D5 model:

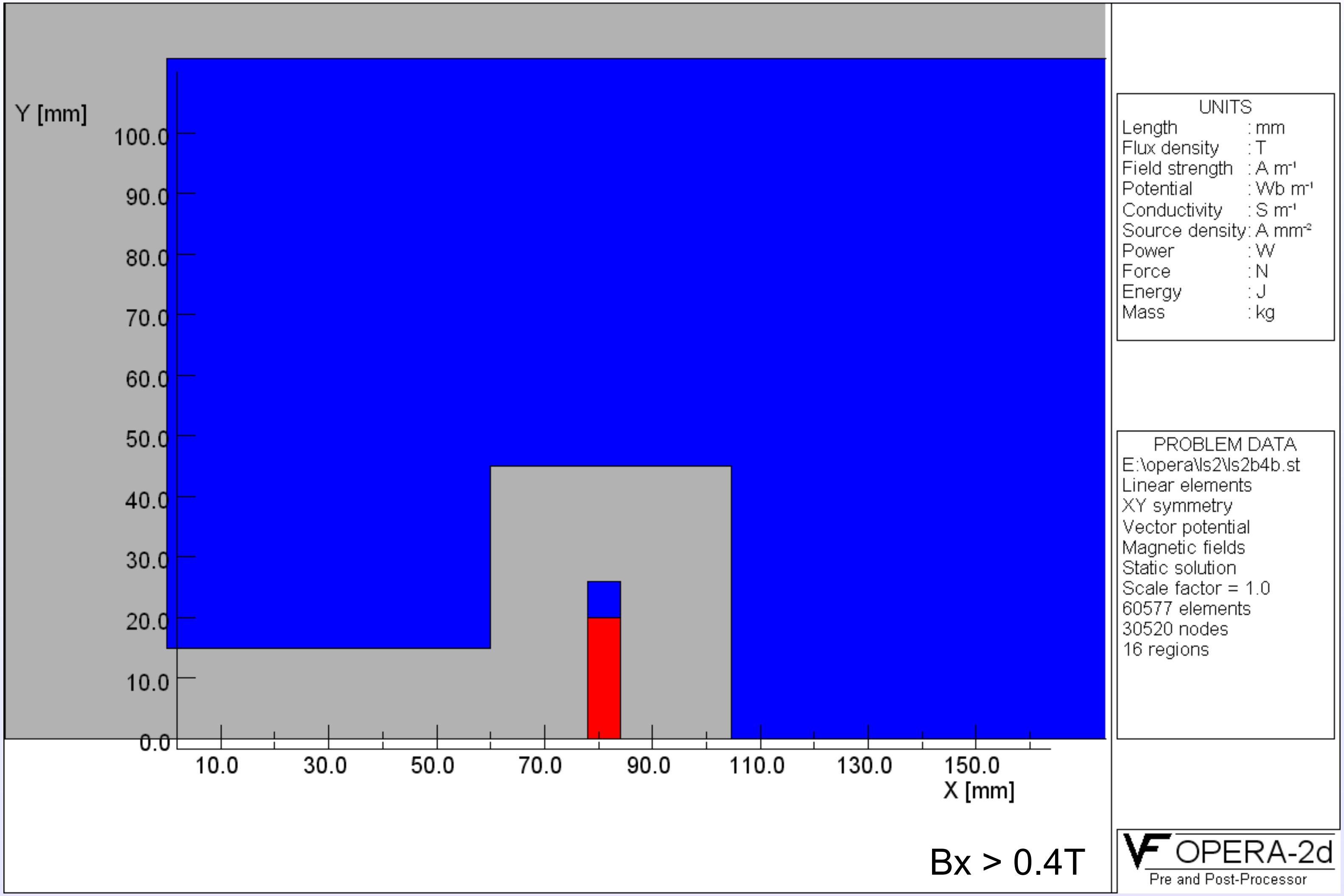
Gap(mm)	Bx(T)	By(T)	B(T)
5	0.28	0.55	0.55
10	0.35	0.53	0.53
15	0.38	0.52	0.52
20	0.40	0.52	0.52
25	0.41	0.52	0.52

Scaling for conductor requirement for Bx=0.41 T is ~0.39 and for Bx=0.28 T is ~0.55.

To avoid inflating conductor cost due to too much conservative costing, I had used a scaling of 0.45 instead of 0.39. Doing this I took credit of some tricks I had in my mind. If I had not done that then the conductor cost for 64k operation would have been ~$33k per magnet instead of ~$29k I mentioned in my earlier e-mail. The scaling of 0.28 (if 5 mm gap can really be accommodated) reduces conductor cost from ~$29 k to ~$24k. In any case ~$29k would be for 1/2" gap rather than 1” gap that George initially gave.

---Ramesh

Iron Cap to Reduce Conductor Requirements



Fringe Field (less than a few Gauss)

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A quick study for fringe field containment. Fringe field is reduced to < few Gauss with 20 mm iron shield.

Perhaps one can reduce thickness or bring it closer.