Feasibility Study-II

Technical Design

Michael S. Zisman
CENTER FOR BEAM PHYSICS

Muon Collaboration Project Manager

Collaboration Meeting–FNAL
May 2, 2001

Outline

- Introduction
- Technical implementation
- R&D program
- Comments on costing
- Summary

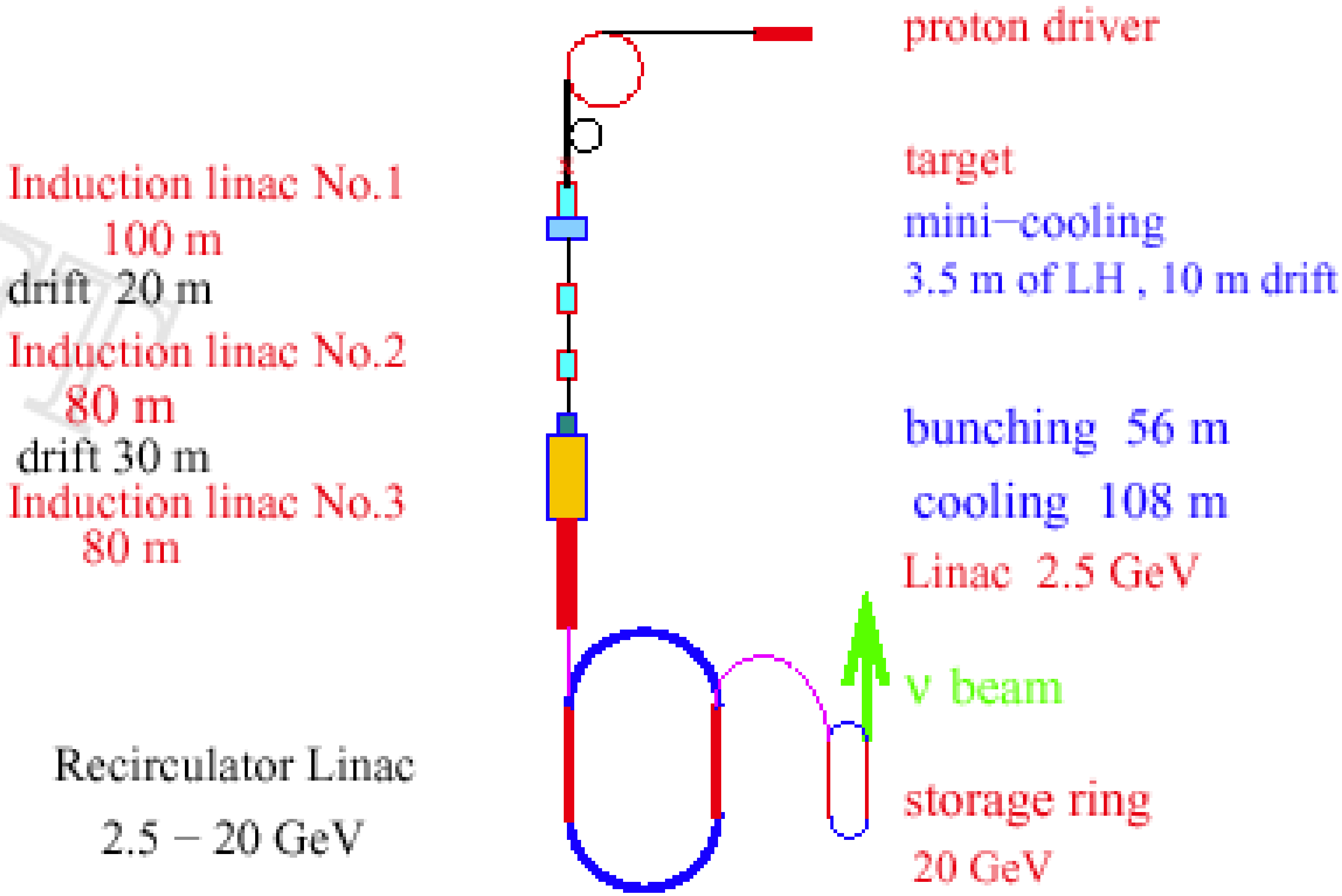
Introduction

- Study-II began in earnest in October, 2000 and ended this week
  - Study Leaders: R. Palmer (Simulations), M. Zisman (Technical and Costing), S. Ozaki (Site Specific, Detector/Physics, and ES&H)
    - Editors met twice in person, weekly via teleconferences, and continuously via e-mail and anguished phone calls
- Initially, main focus was simulation work, with Technical Group providing guidance
  - after parameter list reached dynamic equilibrium, technical design work proceeded
    - iterating with the simulations group as technical parameters became fixed and problems or conflicts developed
- General approach unchanged from Study-I
  - system designs revisited in view of new parameters, e.g., 20 GeV
    - target, induction linacs, buncher and cooling channel, acceleration system, storage ring, detector

Introduction

- Here I will summarize
  - technical implementation of the various systems
    - target, phase rotation, cooling, acceleration, storage ring
  - R&D plans that have arisen as a result of Study-II
  - where we are on costing...but not a number yet
- Team has worked well together in finding solutions to difficult issues
  - solenoids, RF cavities, and absorbers coexist in cooling channel
  - acceleration system can accept the beam from the cooling channel
  - integration of front-end (phase rotation, bunching, and cooling) was done better this time around
    - we learned our lesson from Study-I

Introduction



Introduction

Table 1: Length of the main components of a Neutrino Factory

Component	Length (m)	Total (m)
Target	0.45	0.45
Taper	17.6	17.6
Drift	18	35.6
Induction 1	100	135.6
Drift	3.3	138.9
Mini-Cool	13.5	152.4
Drift	23.2	175.6
Induction 2	80	255.6
Drift	30	285.6
Induction 3	80	365.6
Match to Super FOFO	12	377.6
Buncher	$20 \times 2.75 = 55$	432.6
Cooling part 1	$16 \times 2.75 = 44$	476.6
Match	4.4	481.0
Cooling part 2	$36 \times 1.65 = 59.4$	540.4
Match	22.04	562.4
Linac	433	
RLA arcs min.	2×310	
RLA linacs	2×363.5	
Storage ring arcs	2×53	
Storage ring straights	2×126	

Berkeley Lab

Introduction

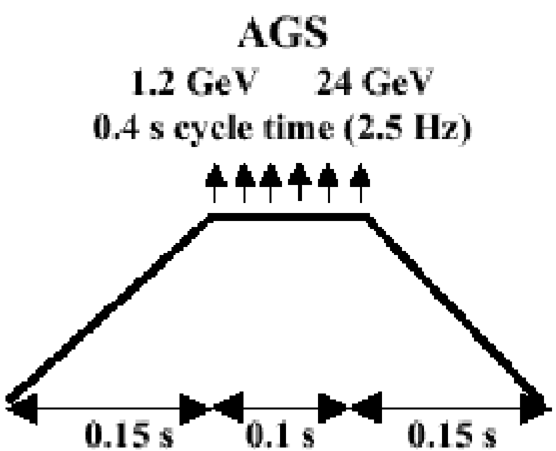
fact ν $\pi\mu$ Muon Collaboration

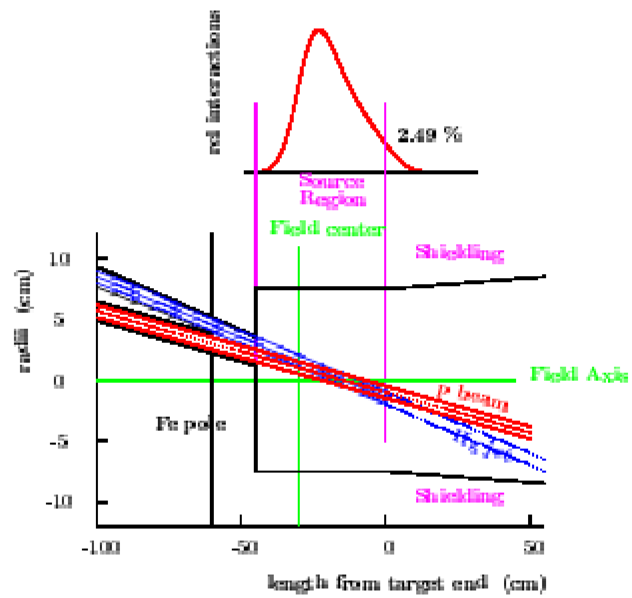
Table 2.1: AGS proton driver parameters.

Total beam power (MW)	1
Beam energy (GeV)	24
Average beam current (μA)	42
Cycle time (ms)	400
Number of protons per fill	1×10^{14}
Average circulating current (A)	6
No. of bunches per fill	6
No. of protons per bunch	1.7×10^{13}
Time between extracted bunches (ms)	20
Bunch length at extraction, rms (ns)	3
Peak bunch current (A)	400
Total bunch area (eVs)	5
Bunch emittance, rms (eV-s)	0.3
Momentum spread, rms	0.005

Technical Implementation

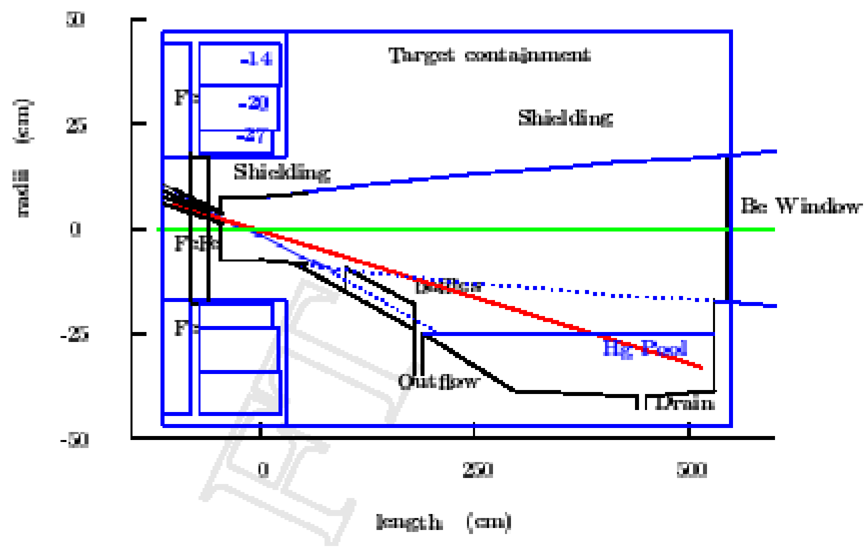
- Target
  - bunch spacing 20 ms
  - design has nozzle well into solenoid field

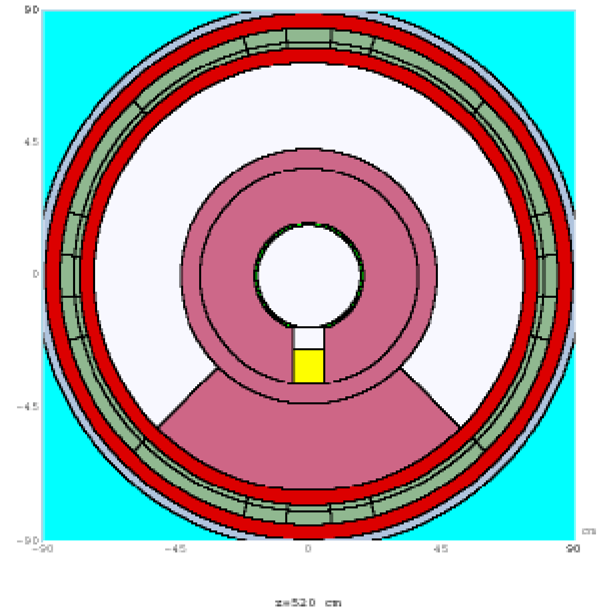




Technical Implementation

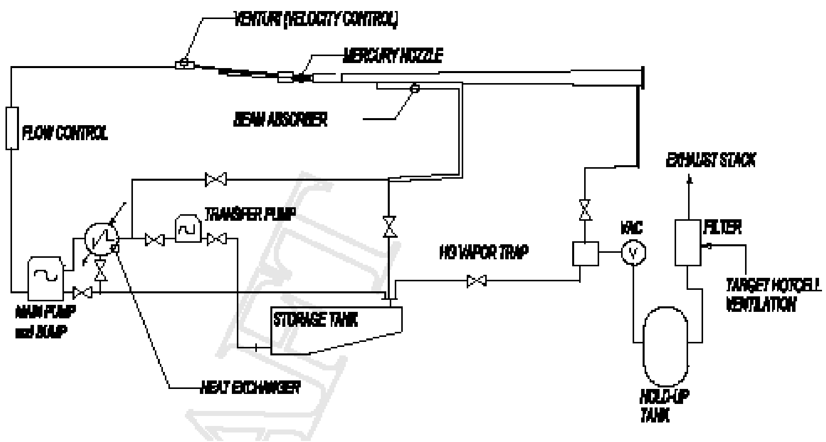
– containment vessel has Be windows and Hg pool beam dump

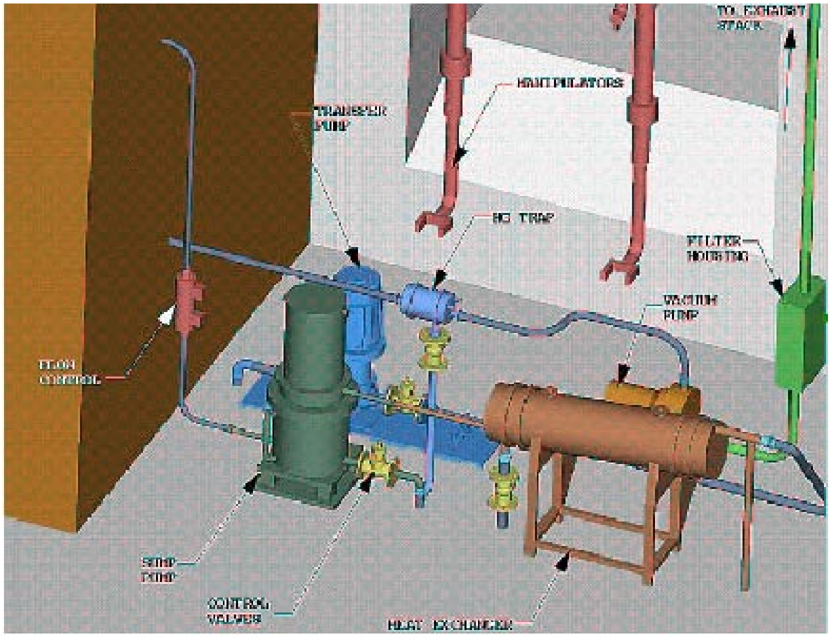




Technical Implementation

— mercury pool and target are a single loop

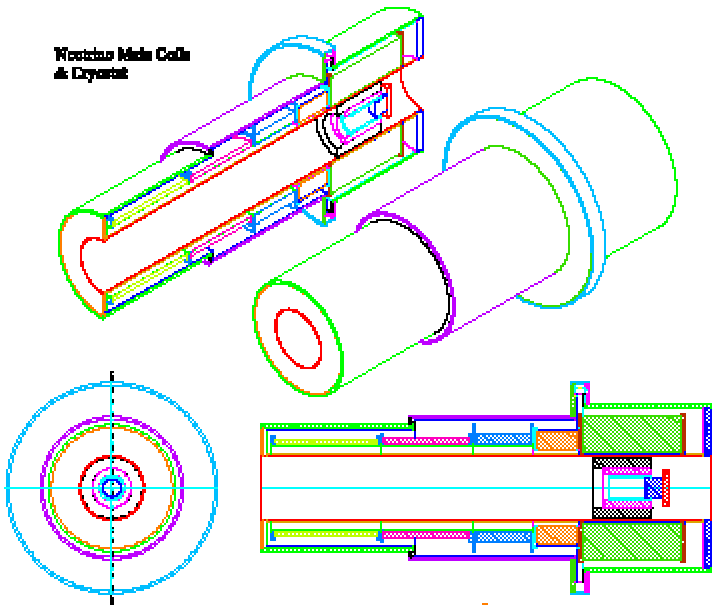


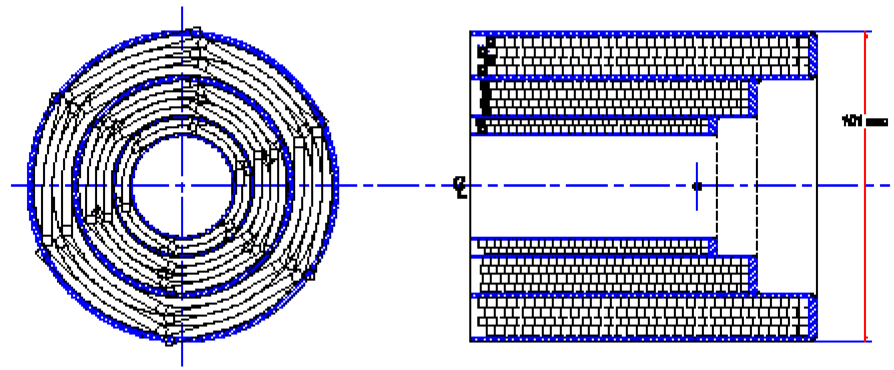


Technical Implementation

– use hollow-conductor insert for target solenoid (provides 6 T)

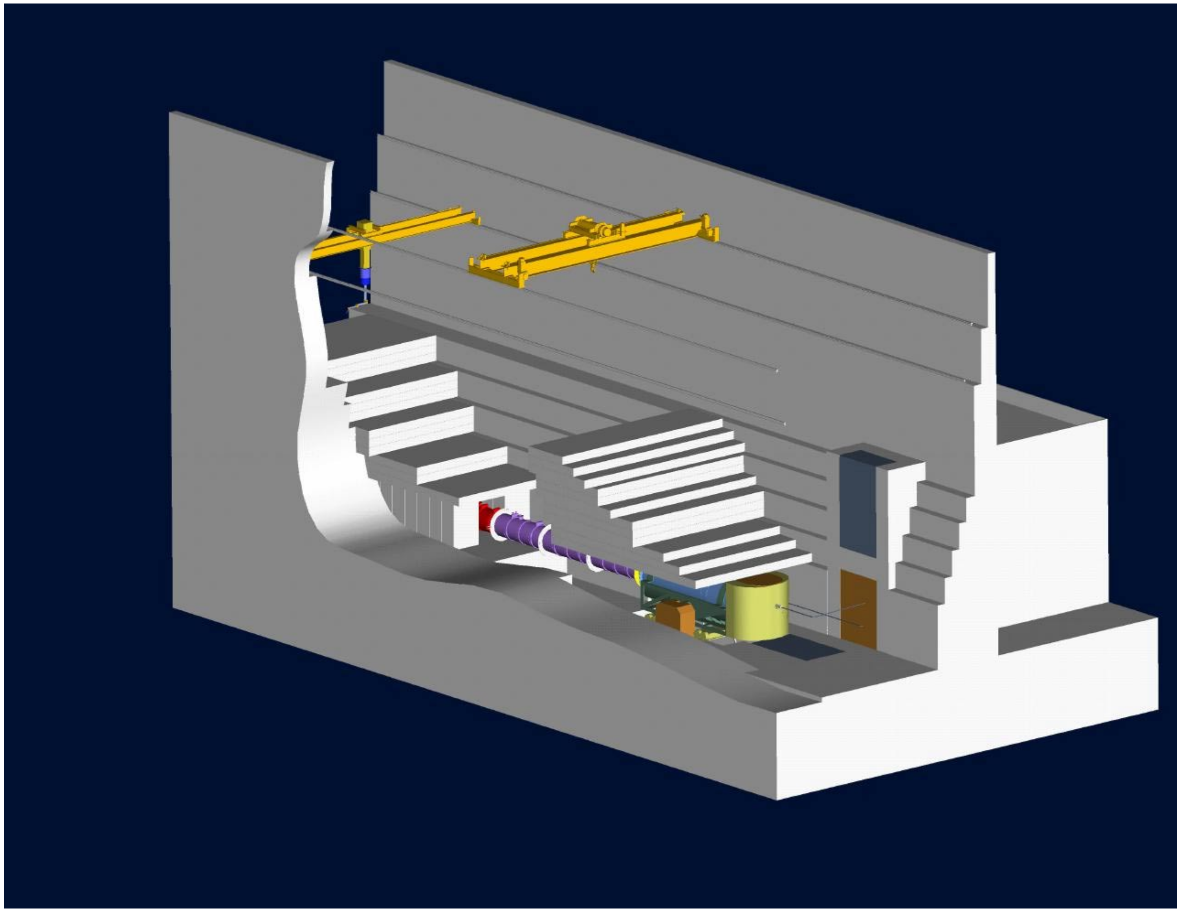
  - long lifetime at expense of low efficiency





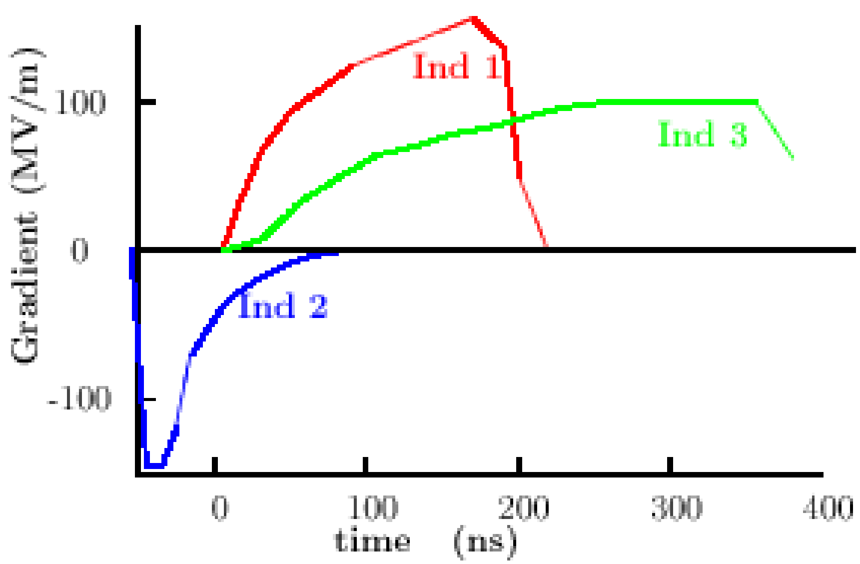
Technical Implementation

- Target facility is a significant aspect of the project



Technical Implementation

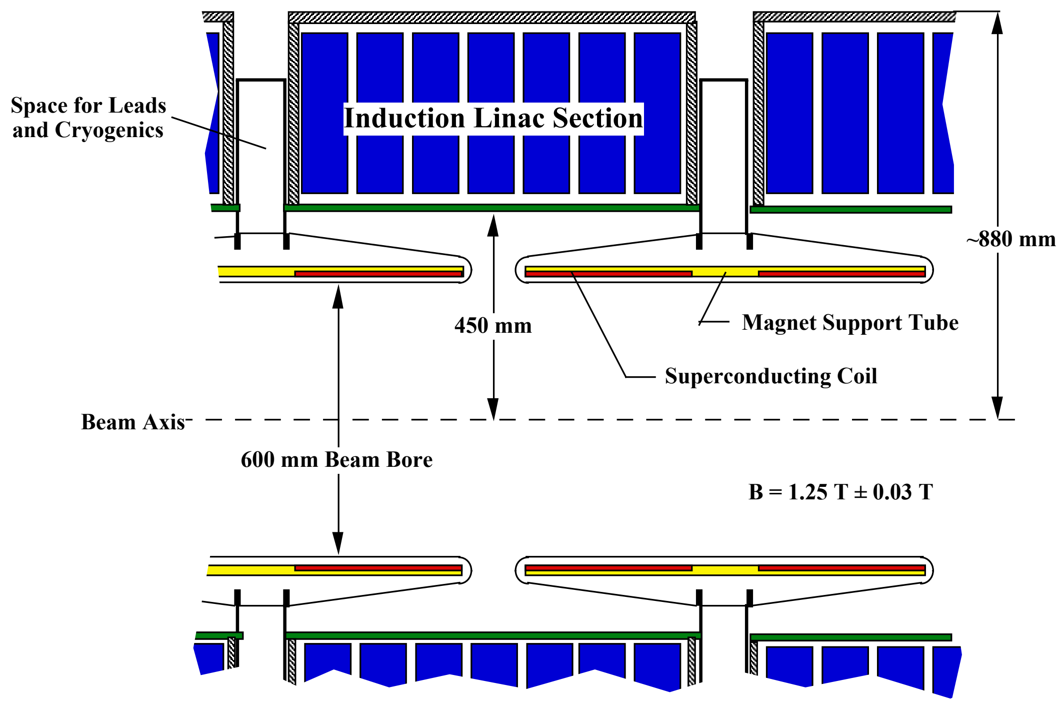
- Phase rotation
  - compared with Study-I, we have less distortion in the phase rotation
    - but this requires more induction linac
    - our implementation uses three IL units, all unipolar
      - cost optimization favors length over gradient



Technical Implementation

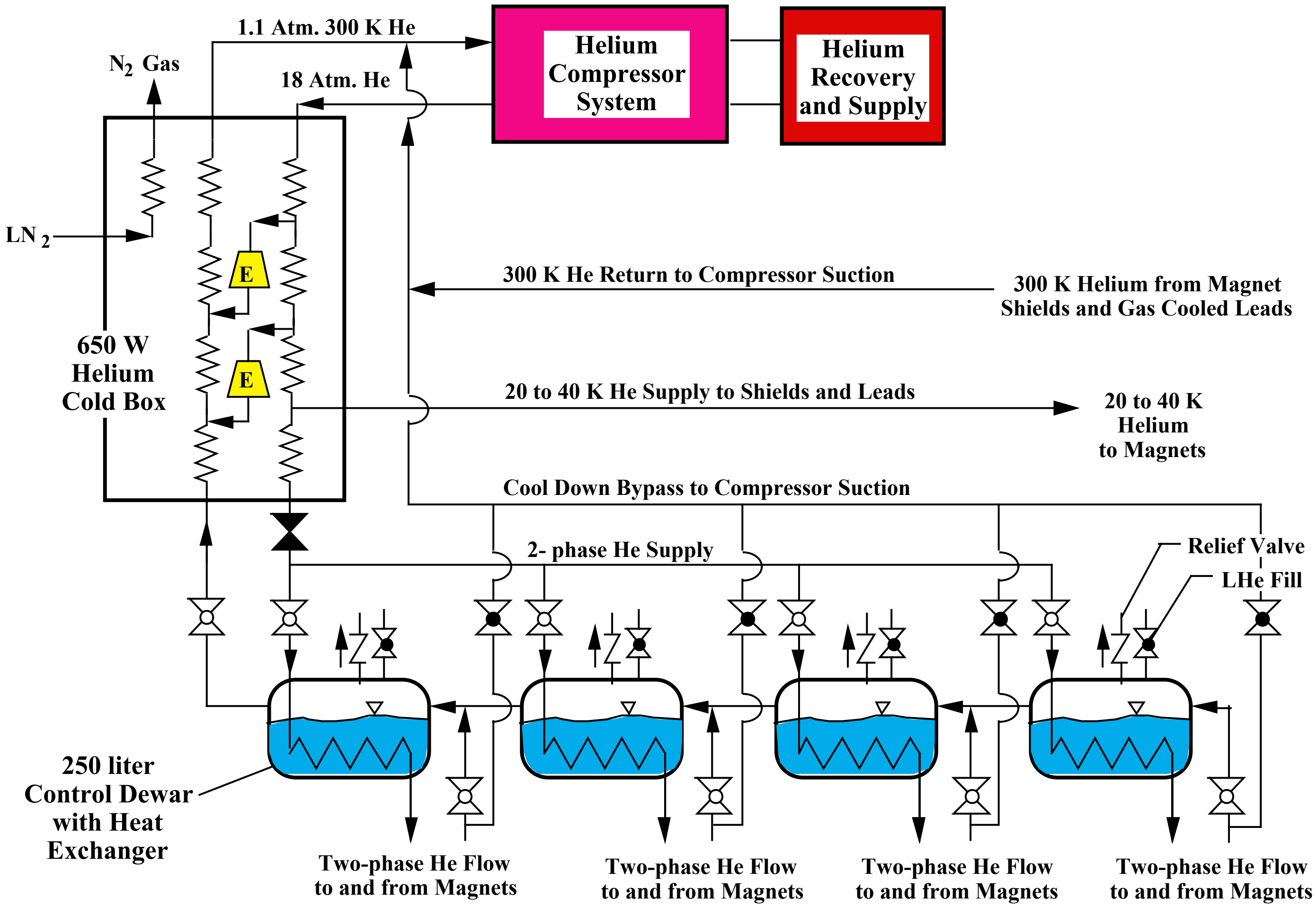
— solenoid periodicity is 0.5 m (validated by simulations)

Cross-section Through a Typical Induction Linac Cell



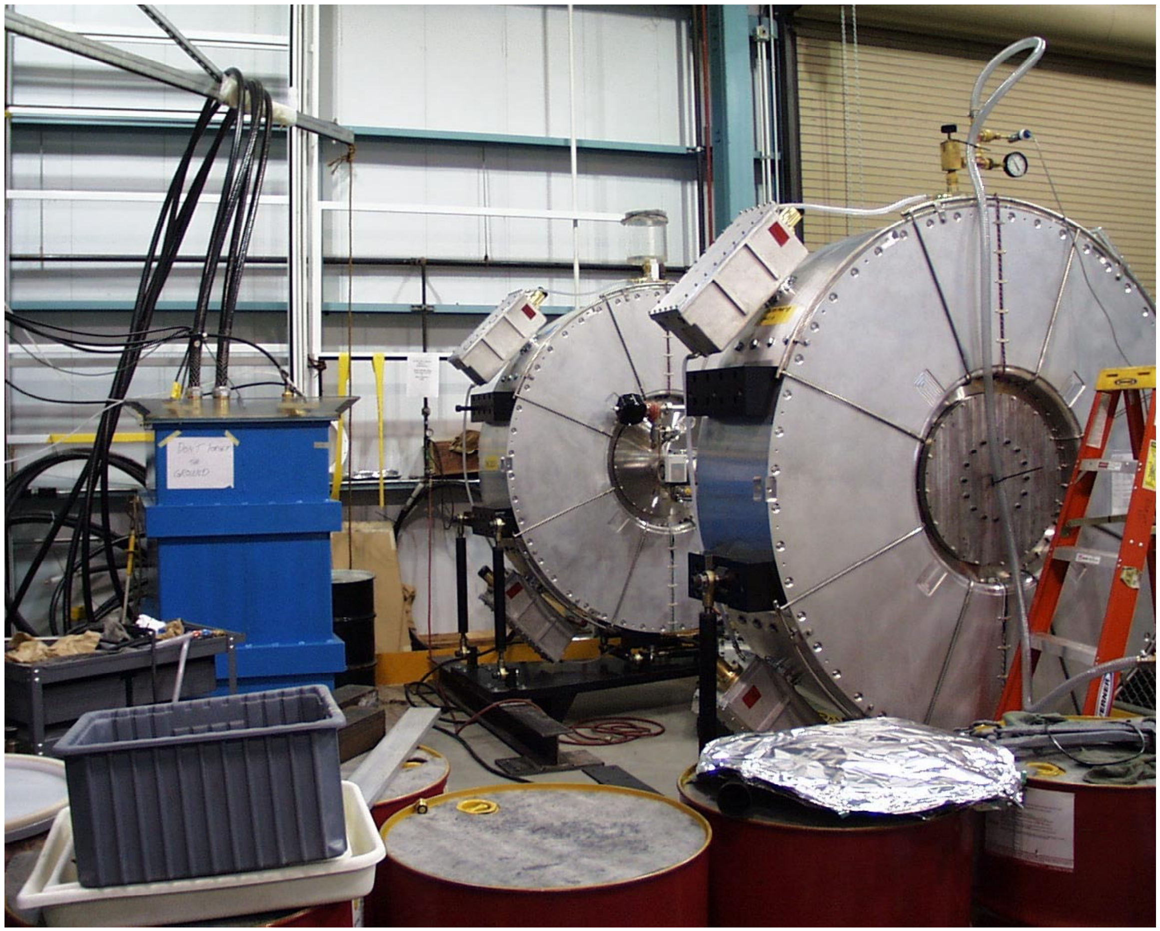
Technical Implementation

Cryogenic Cooling System for One Hundred Phase Rotation Solenoids



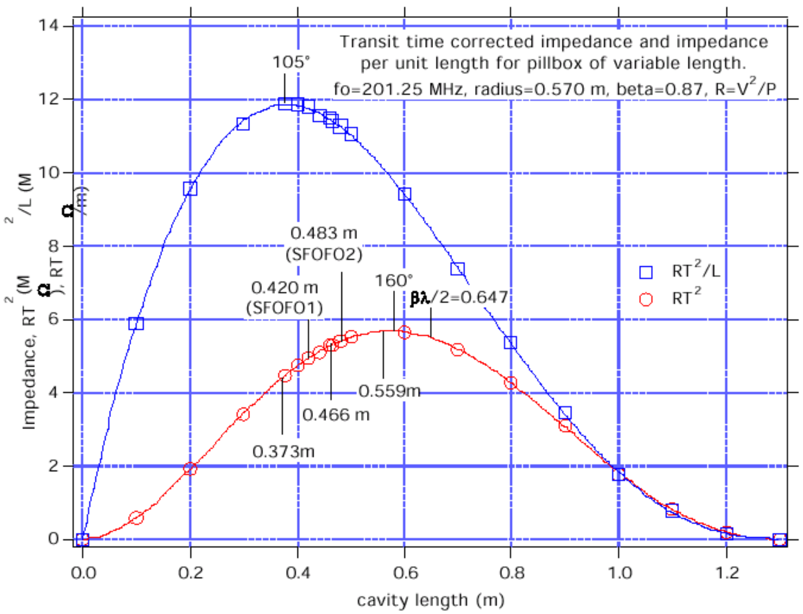
Technical Implementation

– reality check: DARHT cores being built at LBNL



Technical Implementation

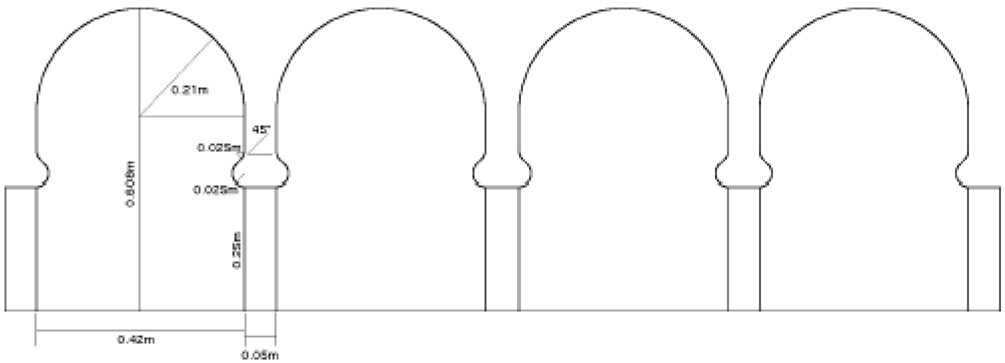
- Buncher and cooling channel
  - cavities based on Be-window design
  - rough optimization of power consumption has been considered
    - peak power consumption of cooling channel RF ≈780 MW
      - average power is only 1.5 MW

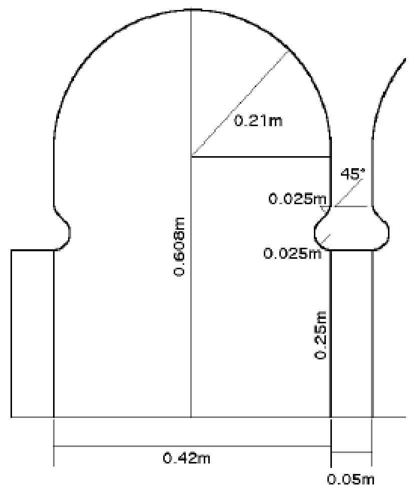


Technical Implementation

— cavities accommodate "stepped" foils (thicker at the outside)

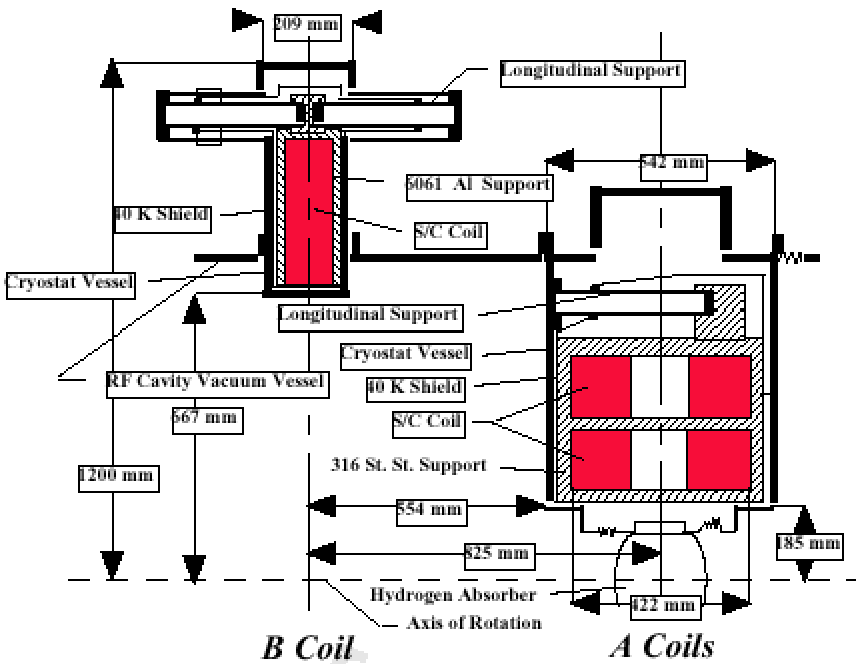
- these are included in the simulations

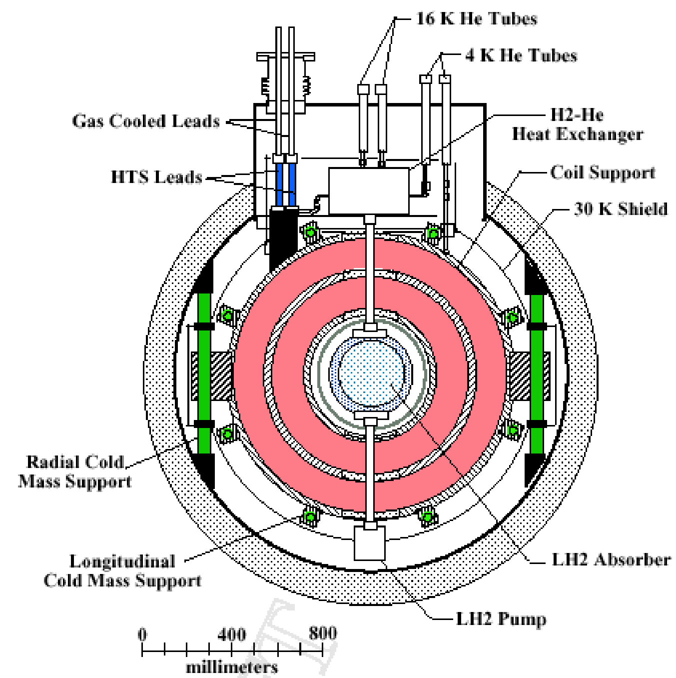




Technical Implementation

- solenoids are mainly straightforward
  - focusing coils in Lattice 2 are a bit too close for comfort



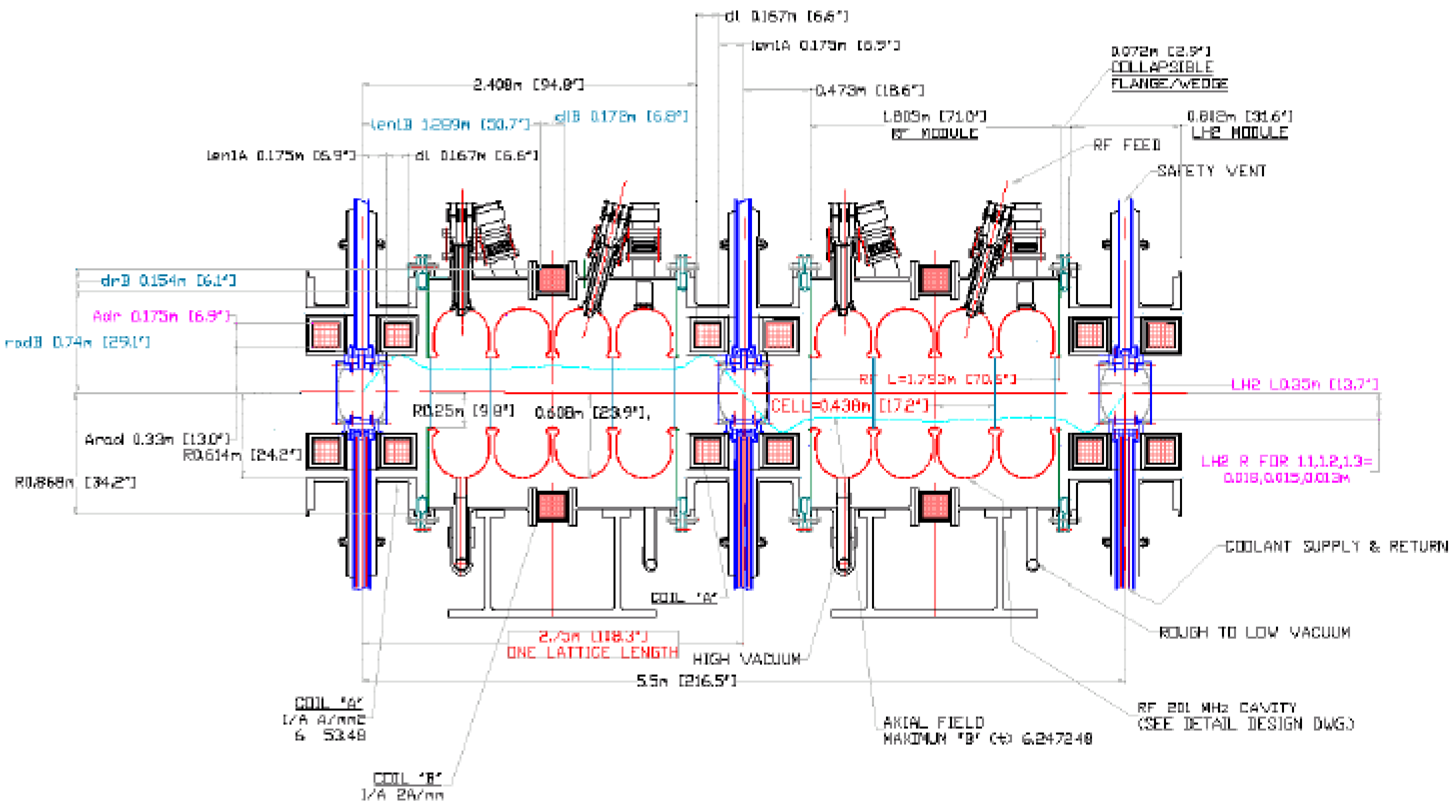


BERKELEY LAB

Muon Collaboration

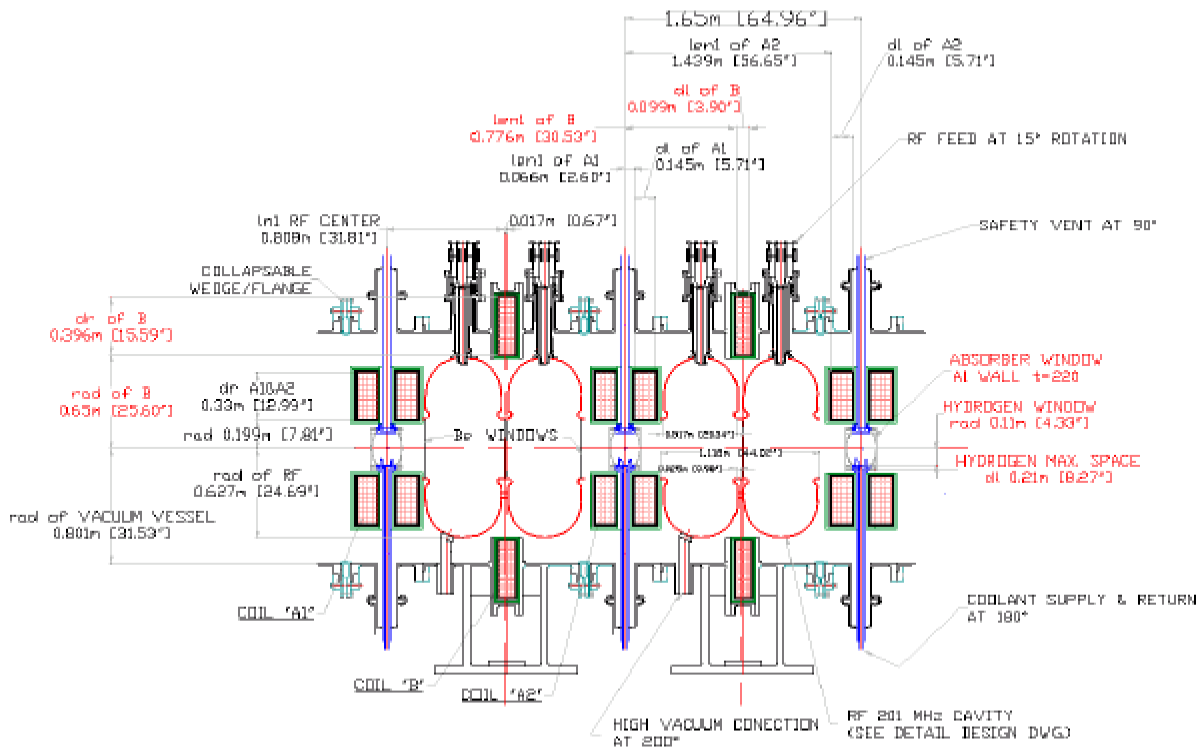
Technical Implementation

– it all fits in cooling channel lattice 1 (2.75 m)



Technical Implementation

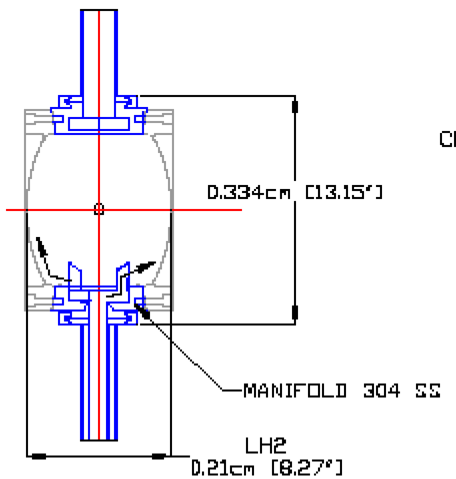
— it's a bit more cheek by jowl in lattice 2 (1.65 m)

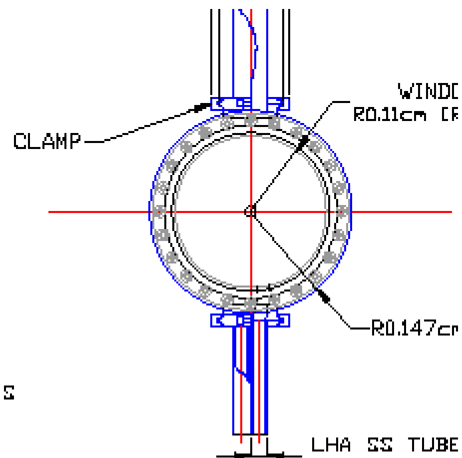


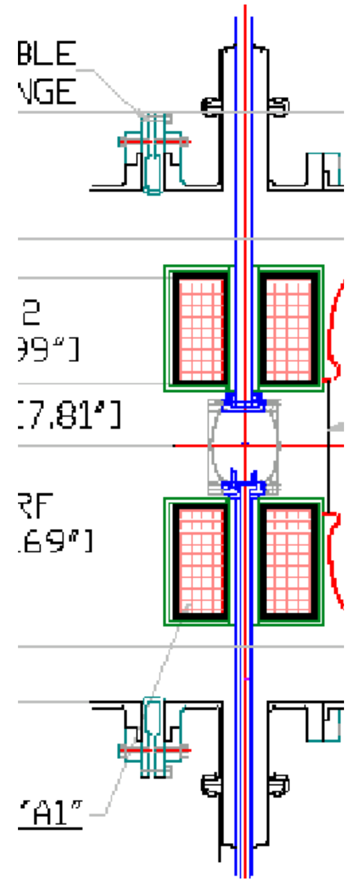
Technical Implementation

– LH_2 absorber mechanical design has been worked out

- a tight fit in lattice 2

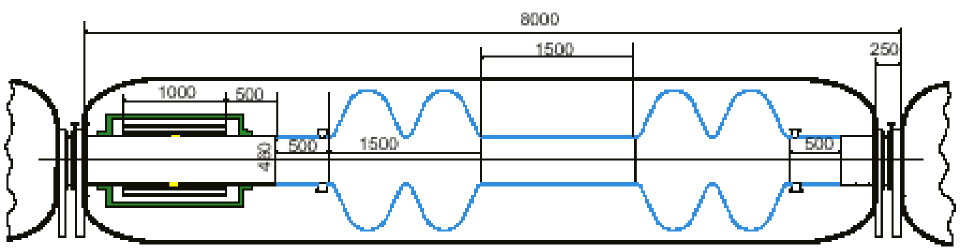




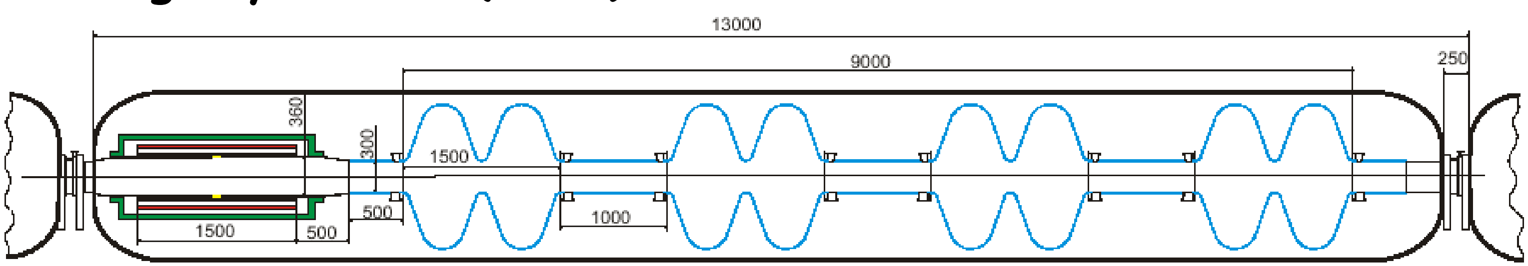


Technical Implementation

- Acceleration
  - initial linac (190→2350 MeV) uses SCRF + solenoidal focusing
    - a few short cryomodules, then intermediate and long modules
      - intermediate cryomodule (8 m)

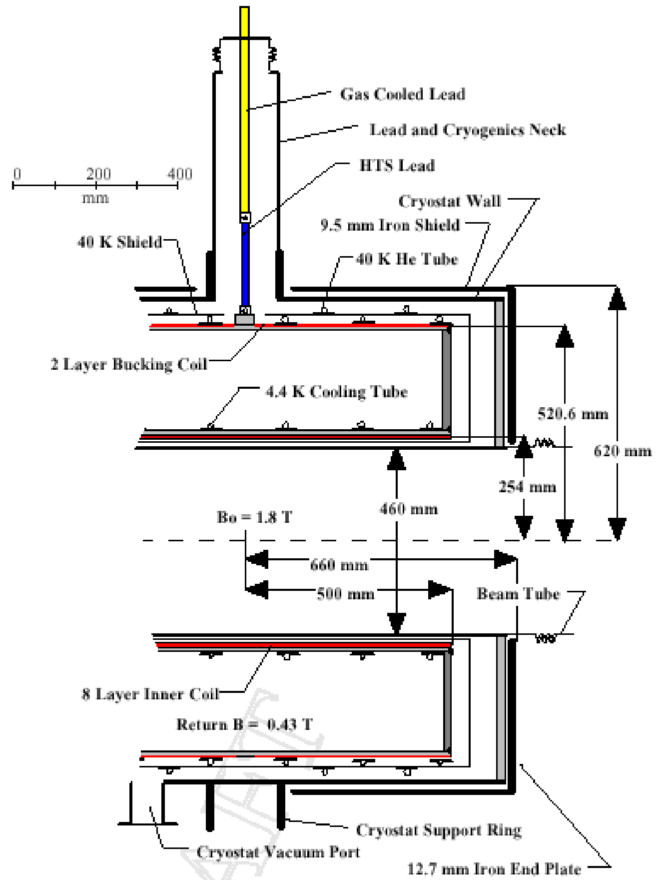


      - long cryomodule (13 m)



Technical Implementation

– minimize fringe field on SC cavities with compensated coil design along with shielding

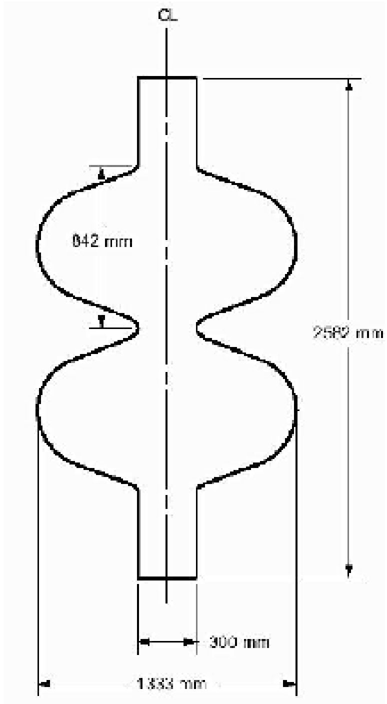


Technical Implementation

- RLA is a 4-pass system with horizontal separation
  - optics is triplet focusing with 3 sextupole families
  - SCRF is 201 MHz operating at high gradients (17 MV/m)
    - linac gain is 2.5 GeV/pass

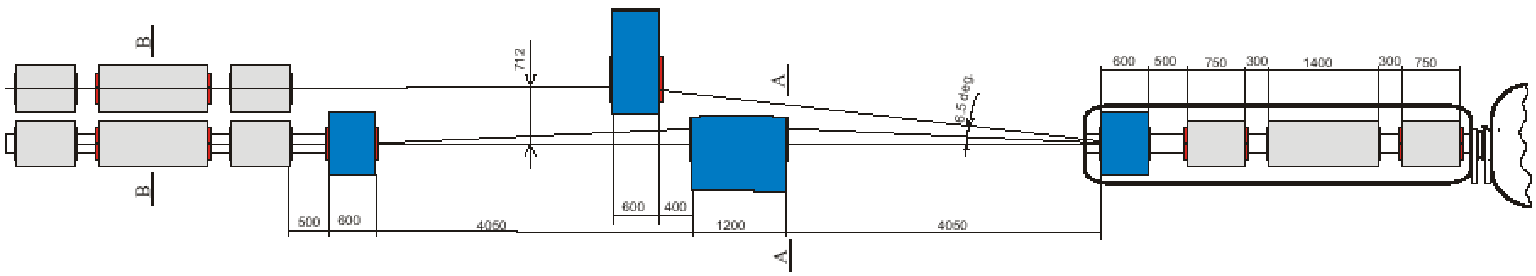
Table 8.6: 2-cell, 300 mm-diameter cavity parameters.

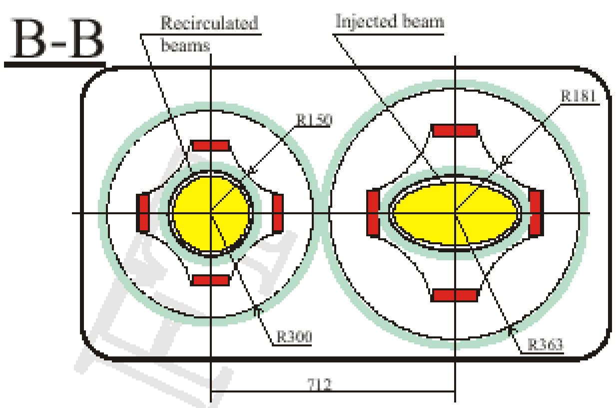
RF freq (MHz)	201.25
No. of cells per cavity	2
Active cavity length (m)	1.5
No. of cavities	256
Linac	76
RLA	180
Aperture diameter (mm)	300
E_{acc} (MV/m)	17
Energy gain per cavity (MV)	25.5
Stored energy per cavity (J)	2008
R/Q (Ω/cavity)	258
E_p/E_{acc}	1.43
H_p/E_{acc} (Oe/MV/m)	38
E_{pk} at 15 MV/m (MV/m)	24.3
H_{pk} at 15 MV/m (Oe)	646
Q_0	6×10^9
Bandwidth (Hz)	200
Input power per cavity (kW)	1016
RF on-time (ms)	3
RF duty factor (%)	4.5
Dynamic heat load per cavity (W)	18.9
Operating temperature (K)	2.5
Q_L	10^6
Microphonics detuning tolerable (Hz)	40
Wall thickness (mm)	8
Lorentz force detuning at 15 MV/m (Hz)	128

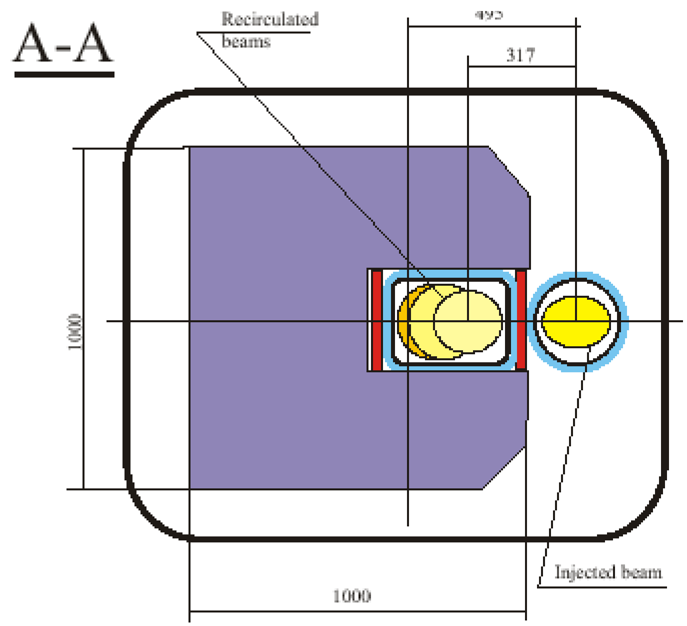


Technical Implementation

- injection scheme has been worked out

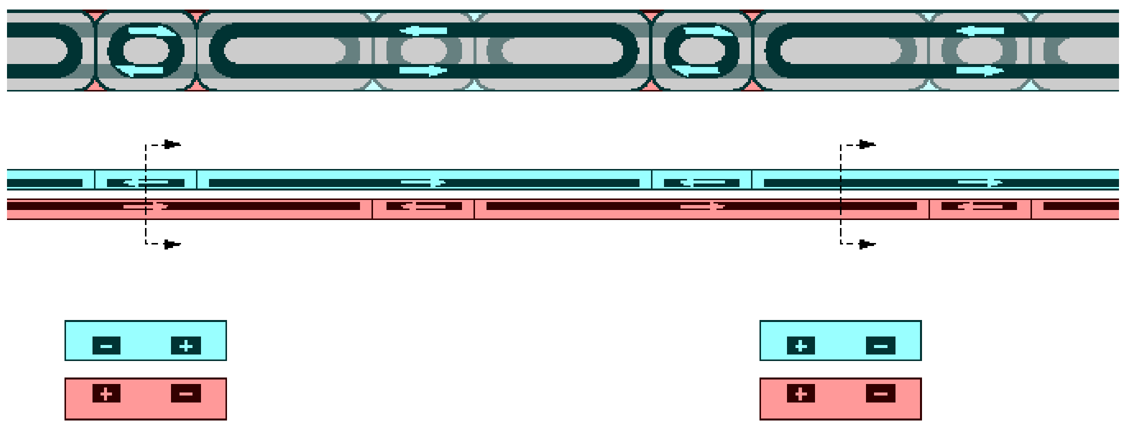






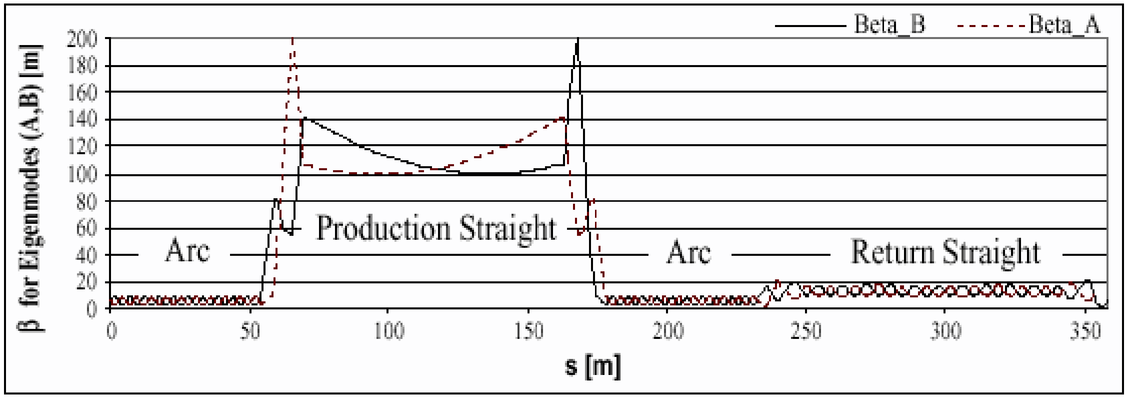
Technical Implementation

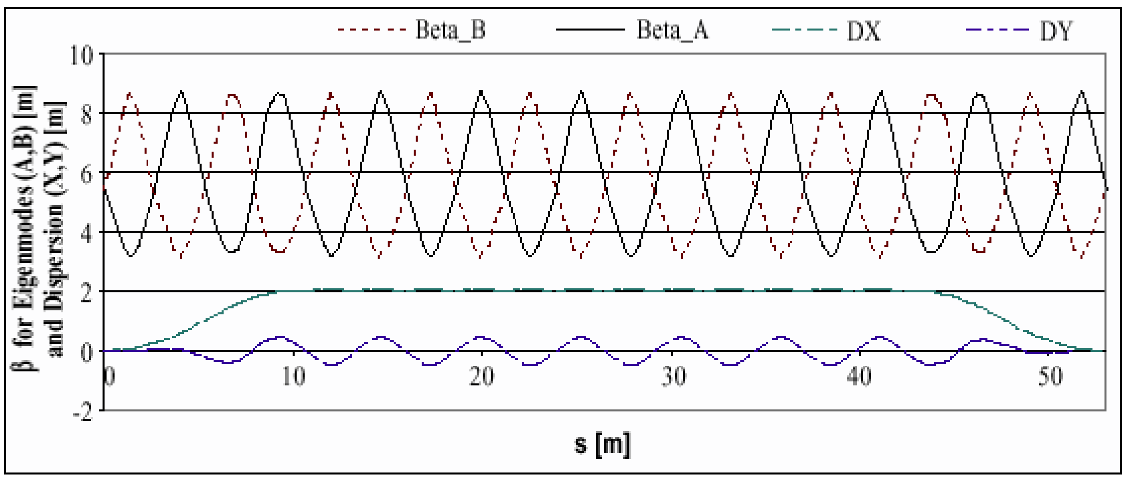
- Storage ring
  - lattice based on skew-quad design with magnet coils off of midplane



Technical Implementation

– lattice for nominal parameters is worked out





R&D Program

- MC has ongoing R&D program aimed at both Neutrino Factory and Muon Collider issues
  - primary emphasis at present is Neutrino Factory topics
- R&D activities fall into four main categories
  - beam simulations/theory (Organizer: Jonathan Wurtele, UCB/LBNL)
  - targetry experiment (E951 at BNL) to demonstrate technical feasibility of key concepts (Organizer: Kirk McDonald, Princeton)
  - MUCOOL to demonstrate feasibility of required components and study cooling effects (Organizer: Steve Geer, Fermilab)
  - component development, e.g.,
    - 201-MHz SCRF cavities; induction linac with internal SC solenoid; 20-T SC target solenoid; muon beam diagnostics
- Study-II has added some topics to the ongoing MC R&D program
  - only key Study-II-related items will be covered here

R&D Program

- Target
  - establish survivability of target in 1 MW (4 MW) beam
    - ditto for beam containment windows
  - optimize target solenoid field level
  - examine radiation effects on materials
- Phase rotation
  - measure influence of SC solenoid on IL core
  - optimize core material
  - demonstrate required pulser design; investigate branched device
  - evaluate alternative mini-cooling absorbers (water-cooled Be or Li)

R&D Program

- Bunching and Cooling
  - validate hardware designs (RF cavity, absorber, solenoid)
    - develop cost-effective manufacturing techniques
  - examine alternative to foils for cavity ends (grid of tubes)
  - develop RF power source (MBK or other)
  - develop required diagnostics to operate cooling channel
  - complete study on "double-flip" approach
  - continue simulations to enhance performance and reduce cost
    - examine possibilities for longitudinal cooling

R&D Program

- Acceleration
  - validate high-gradient SC cavity design, plus tuner and coupler
    - mechanical stiffness
    - 17 MV/m at $Q = 6 \times 10^9$
  - develop cost-effective fabrication techniques
  - develop solenoid with adequately low fringe field
- Storage ring
  - evaluate multipole content of the magnetic field
    - complete tracking studies of "non-standard" SR lattice
  - evaluate cost-benefit tradeoffs of standard compact lattice
  - develop optics to "hide" matching section from detector

Comments on Costing

- Cost estimate for facility was supposed to be ready now
  - but it isn't (yet)
- This will be done before Snowmass, and will be included in the report
- Costing will be "top-down" not bottom-up
  - consider only direct costs, without contingency
- Expect overall cost to be lower than in Study-I (50 GeV $\rightarrow$ 20 GeV)
  - for 6 times higher intensity

Summary

- Building on Study-I design, we have developed a high-performance Neutrino Factory design
- Technical approaches have been identified that will provide the required performance
- The proposed design is compatible with being sited at BNL
  - — or even at another large national laboratory in the Midwest
- An R&D plan addressing issues raised in Study-II has been formulated
- Study Leaders (Palmer, Ozaki, MZ) are very appreciative of the efforts that have gone into the Study
  - — and the support from BNL management and the *MC*