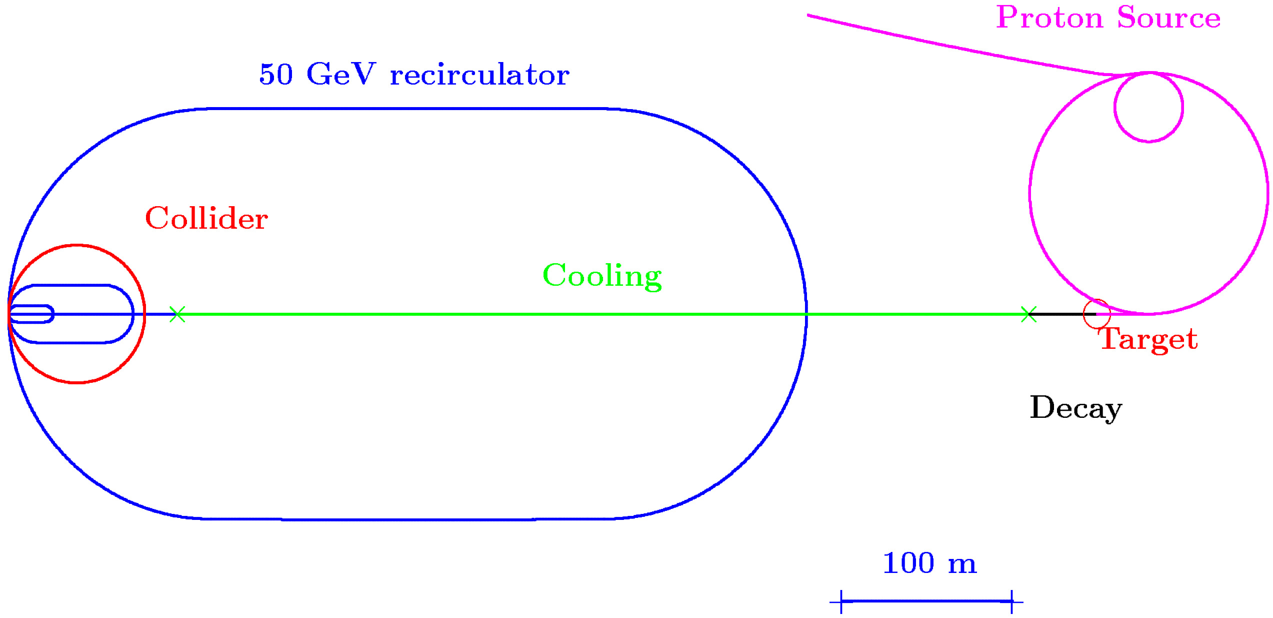
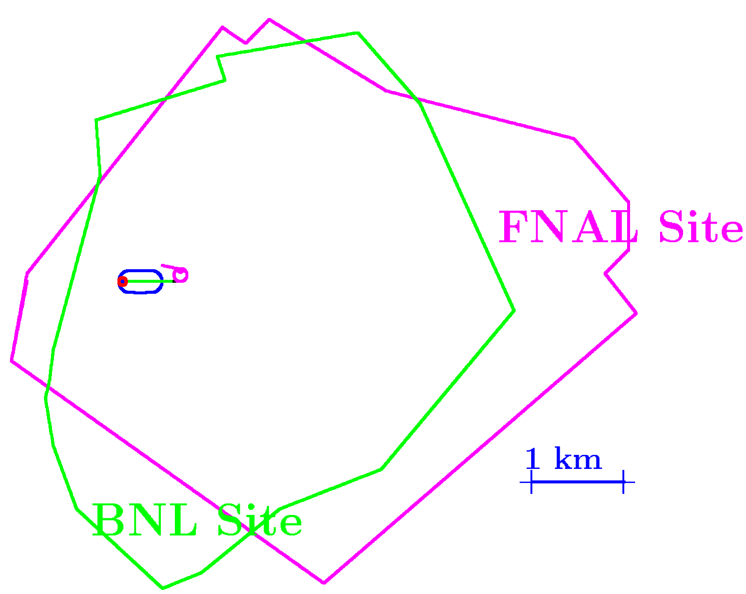
Neutrino factory and muon colliders in the USA

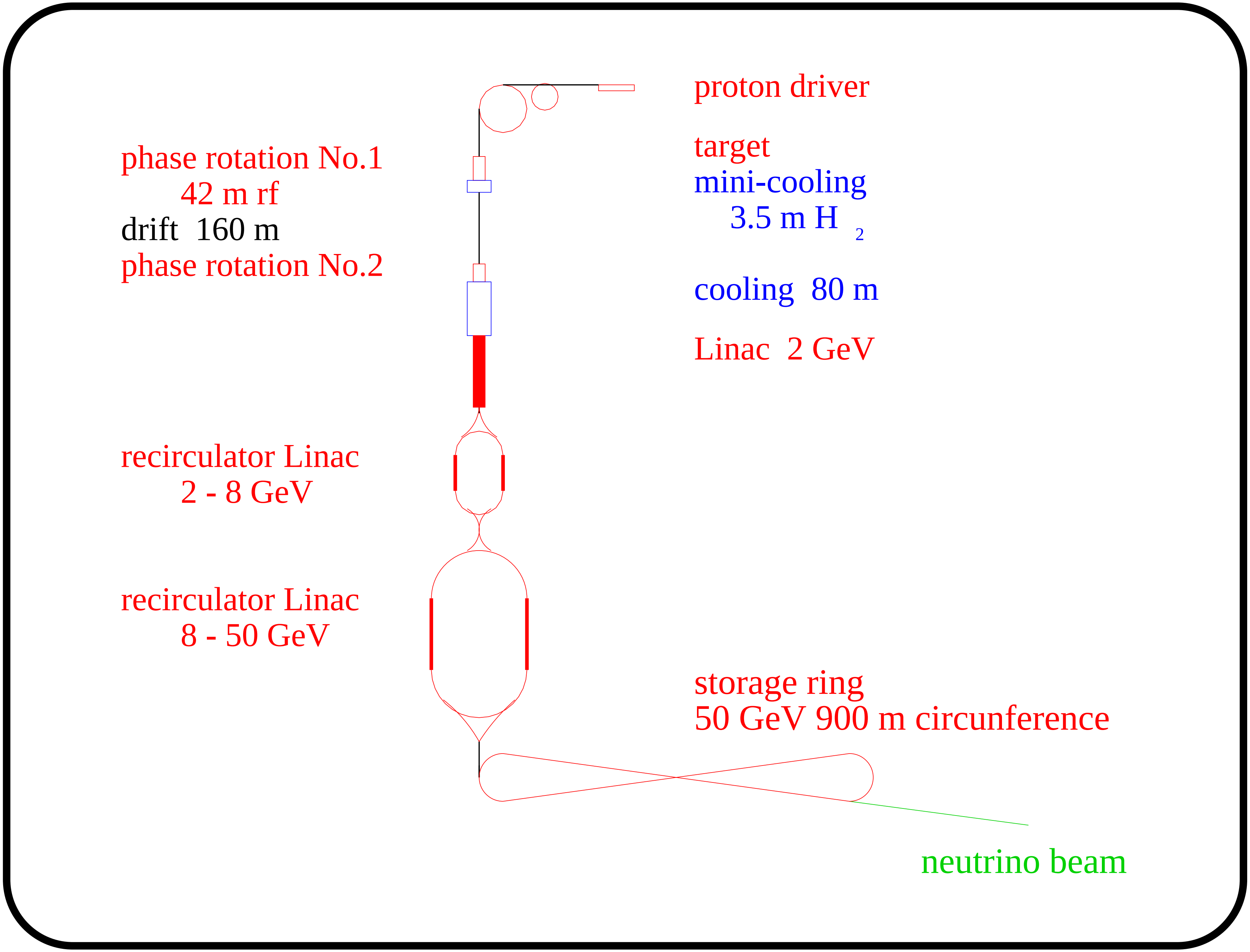
Harold G. Kirk
Brookhaven National Laboratory

PLENARY MEETING on MUON MACHINES
CERN
September 20, 1999

100GeV HIGGS COLIDER






proton driver
target
mini-cooling
3.5 m H 2
cooling 80 m
Linac 2 GeV
phase rotation No.1
42 m rf
drift 160 m
phase rotation No.2
recirculator Linac
2 - 8 GeV
recirculator Linac
8 - 50 GeV
storage ring
50 GeV 900 m circunference
neutrino beam

Neutrino Factory and Muon Colliders

Key Systems

Proton Driver:BNL,FNAL

Capture System:BNL,CERN,LBL,Princeton

Phase Rotation:BNL,CERN,LBL,Princeton

Ionization Cooling:BNL,FNAL,IIT,LBL

Acceleration:BNL,CERN,FNAL

Storage Ring:BNL,CERN,FNAL

Collider:BNL,FNAL

Detectors:BNL,FNAL

Proton Driver

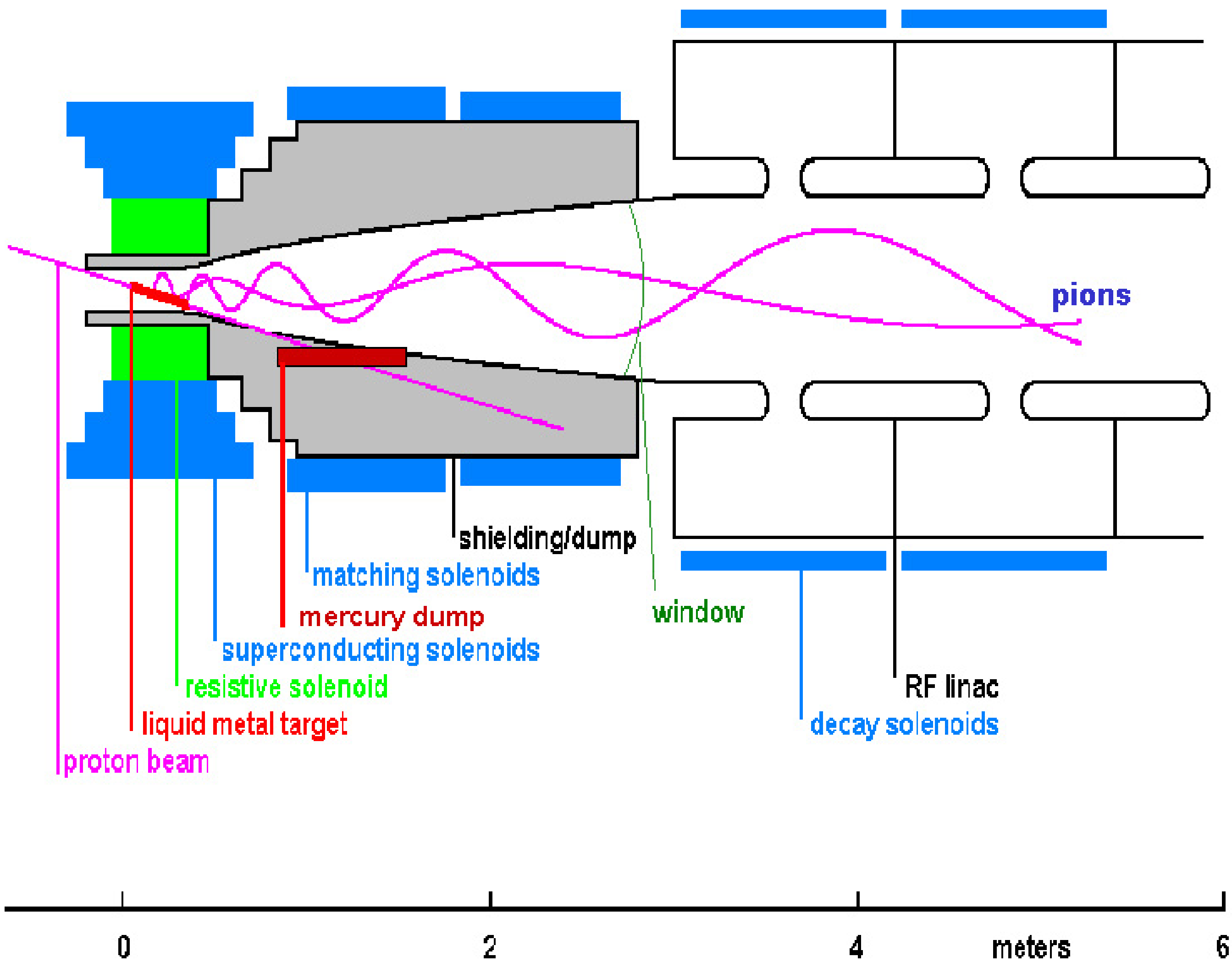
BNL,FNAL

Energy	GEV	24	24	16	16
Power	MW	1	4	1	4
Repetition	Hz	2.5	5	15	15
p's/fill		10^{14}	$2\ 10^{14}$	$2.5\ 10^{13}$	10^{14}
bunches		6	6	4	4
circ.	m	807	807	474	474
spacing	m	135	135	118	118
sigma t	nsec	1	1	1	1

Key Components

- BNL-2.5 GeV Accumulator, 600 MeV Linac, 2nd 2.5 GeV Booster
- FNAL-1 GeV Linac, 3 GeV Prebooster, 16 GeV Booster

Overview of Targetry for a Muon Collider



- 1.2×10^{14} $\mu^{\pm}$/s via π-decay from a 4-MW proton beam.
- Proton pulse $\approx$ 1 ns rms for a muon collider.
- Mercury jet target.
- 20-T capture solenoid followed by a 1.25-T π-decay channel with phase-rotation via rf (to compress energy of the muon bunch).

The Hybrid
20 T Solenoid

Strategy

20 T + r=7.5cm $\Longrightarrow$ $P_t \leq$ 225 MeV/c

Solenoid Attributes

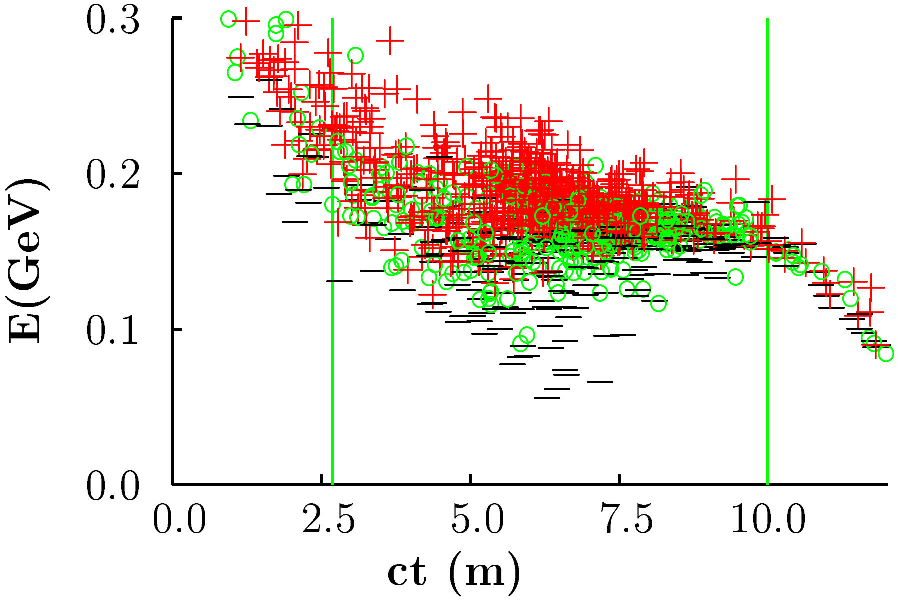
- Shielding
  - 15 cm ID – 24 cm OD
- Inner Coil
  - Resistive coil
  - 4 MW
  - 6 T
  - 24 cm ID – 60 cm OD
- Outer Coils
  - Superconducting
  - 14 T
  - 60 cm ID

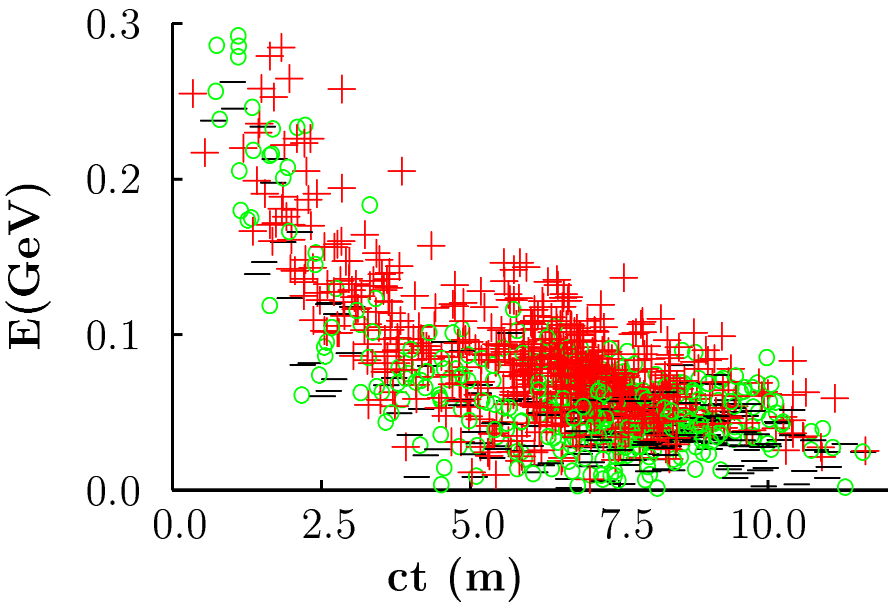
Matching section

20 T $\rightarrow$ 1.25 T — warm bore 7.5cm $\rightarrow$ 30cm

Phase Rotation

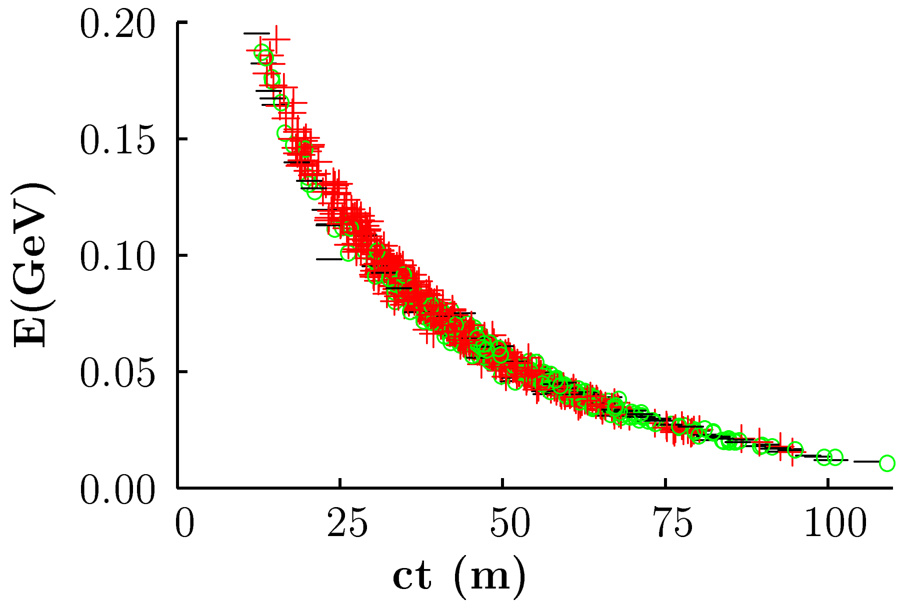
Strategy

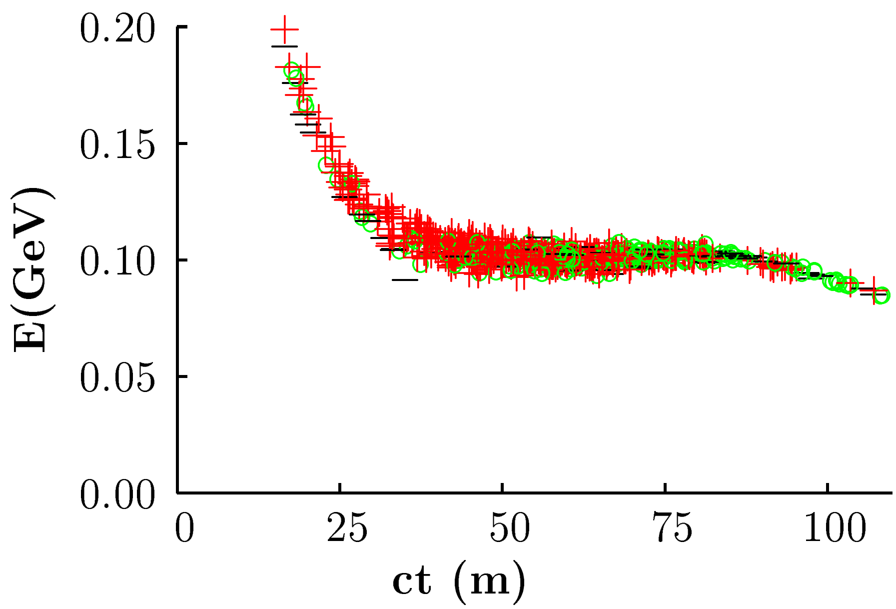




Phase Rotation

Drift and Induction Linac





Summary of Low Frequency Cavities

Gradients used in various models

	Parmela Kirk	MCMuon Palmer	ICOOL Fukui	MCMuon Palmer
Freq MHz		$< E >$ MV/m		
100	4.5			
90	4.2		4	
60	3.6	5		8
50	3.3		5	
45	3.3			7
30	2.1	4	4	5

Capture Issues

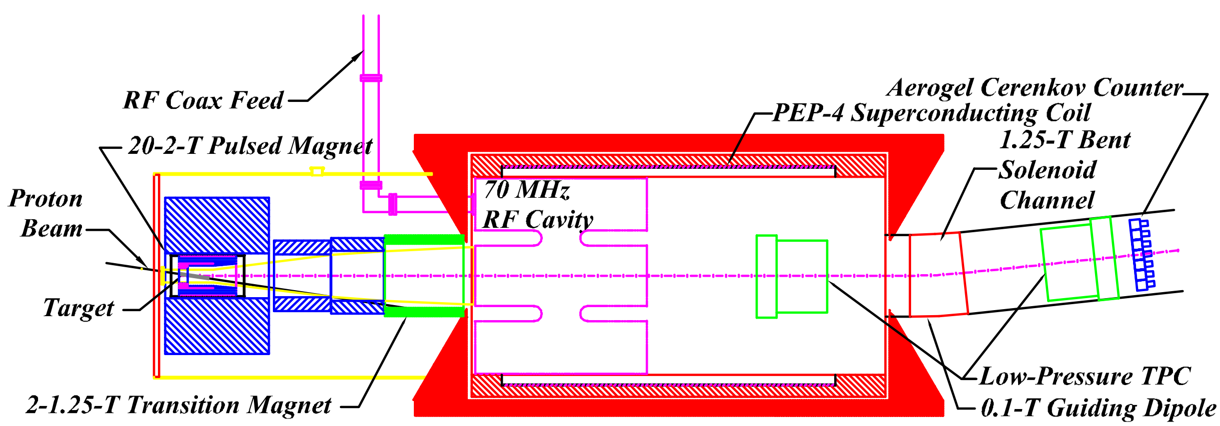
- Yield and spectra of low-energy pions
- Operation of a 20 T SC solenoid surrounding a ≈ 4 MW target
- Operation of rf cavity in high radiation environment
- High-gradient pulsed operation of low-frequency rf cavities

The Target Experiment

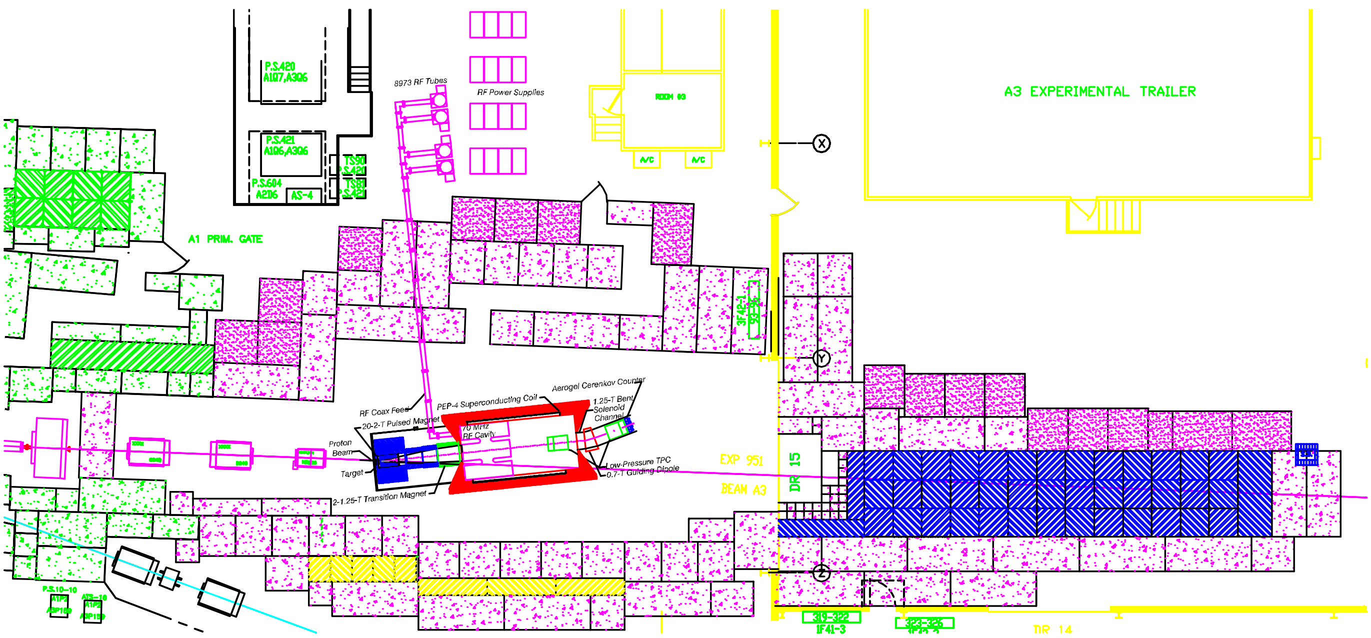
BNL,CERN,LBL,Princeton

Key Components

- 1.4 cm diameter liquid Hg jet
- 20-T Pulsed Solenoid
- 70 MHz rf cavity
- 1.25-T 2m ID Solenoid
- 1.25-T solenoidal diagnostic channel

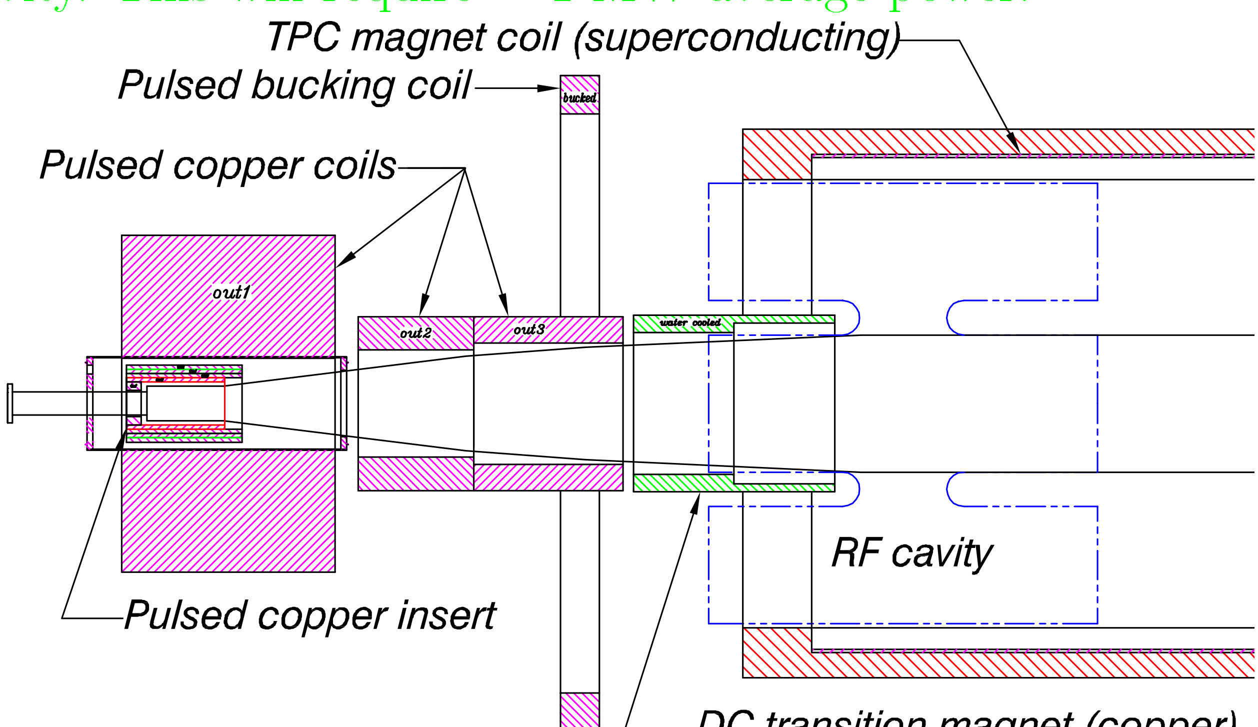


Experiment Layout
in the AGS A3 Line

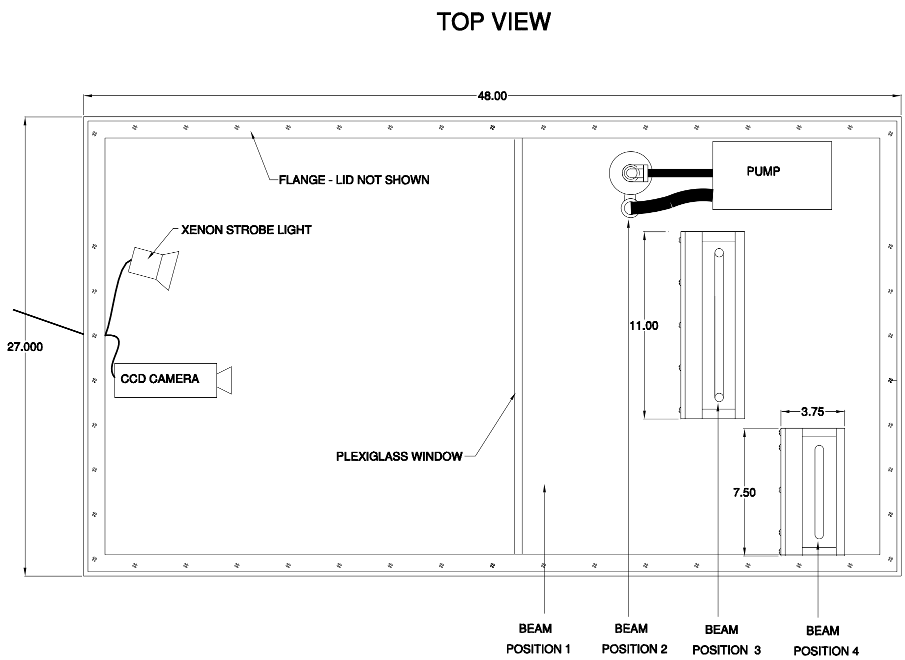


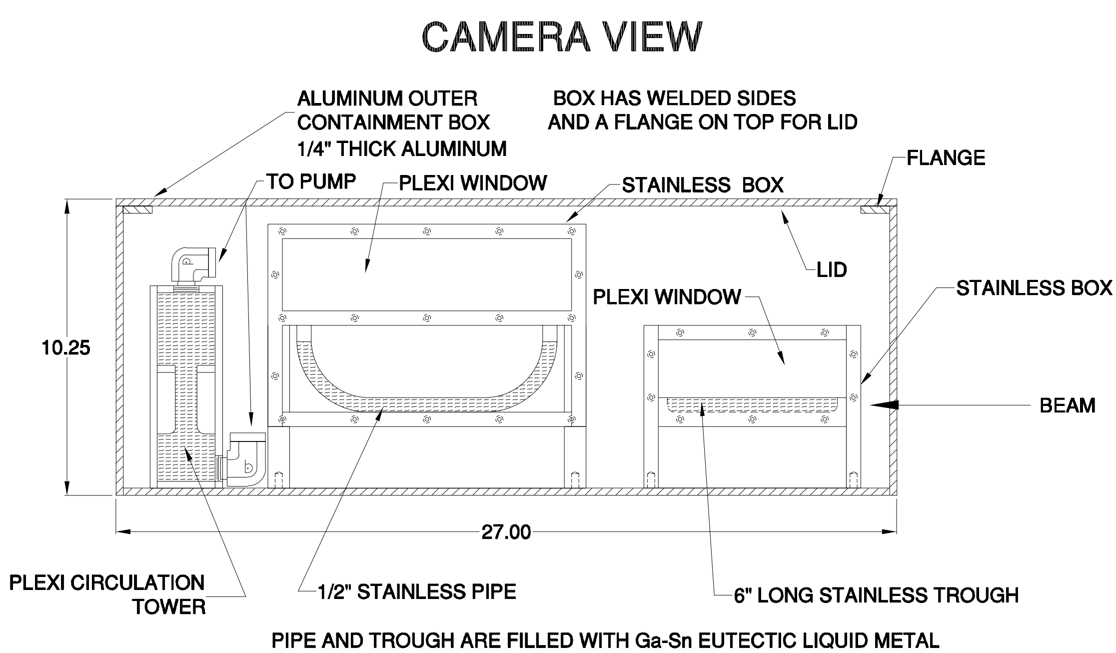
Issues, 4: Pulsed 20-T Magnet

- The copper magnet will be cooled by LN_2, and can be pulsed once every 10 minutes. Pulse duration $\approx$ 1 s.
- Engineer: Bob Weggel, designer: Bob Duffin.
- 4 MW (peak) power to be bussed from the MPS power supply house to the A3 line (Andy Soukas).
- 100 liters of LN_2 boiled off each pulse; vent outside of cave.
- A DC magnet is required as a transition between the pulsed magnet and the DC superconducting magnet around the rf cavity. This will require $\approx$ 1 MW average power.



Initial Beam/Liquid Experiment





Schedule

- FY99:

  Prepare A3 area; begin work on liquid jets, extraction upgrade, magnet systems, and rf systems.

- FY00:

  Initial beam tests in A3 line. Liquid jet test at NHMFL. (600 hours of AGS beamtime).

- FY01:

  Complete extraction upgrade; test of liquid jet + beam. (600 hours).

- FY02:

  Complete magnet and rf systems; test with 2 ns beam. (600 hours).

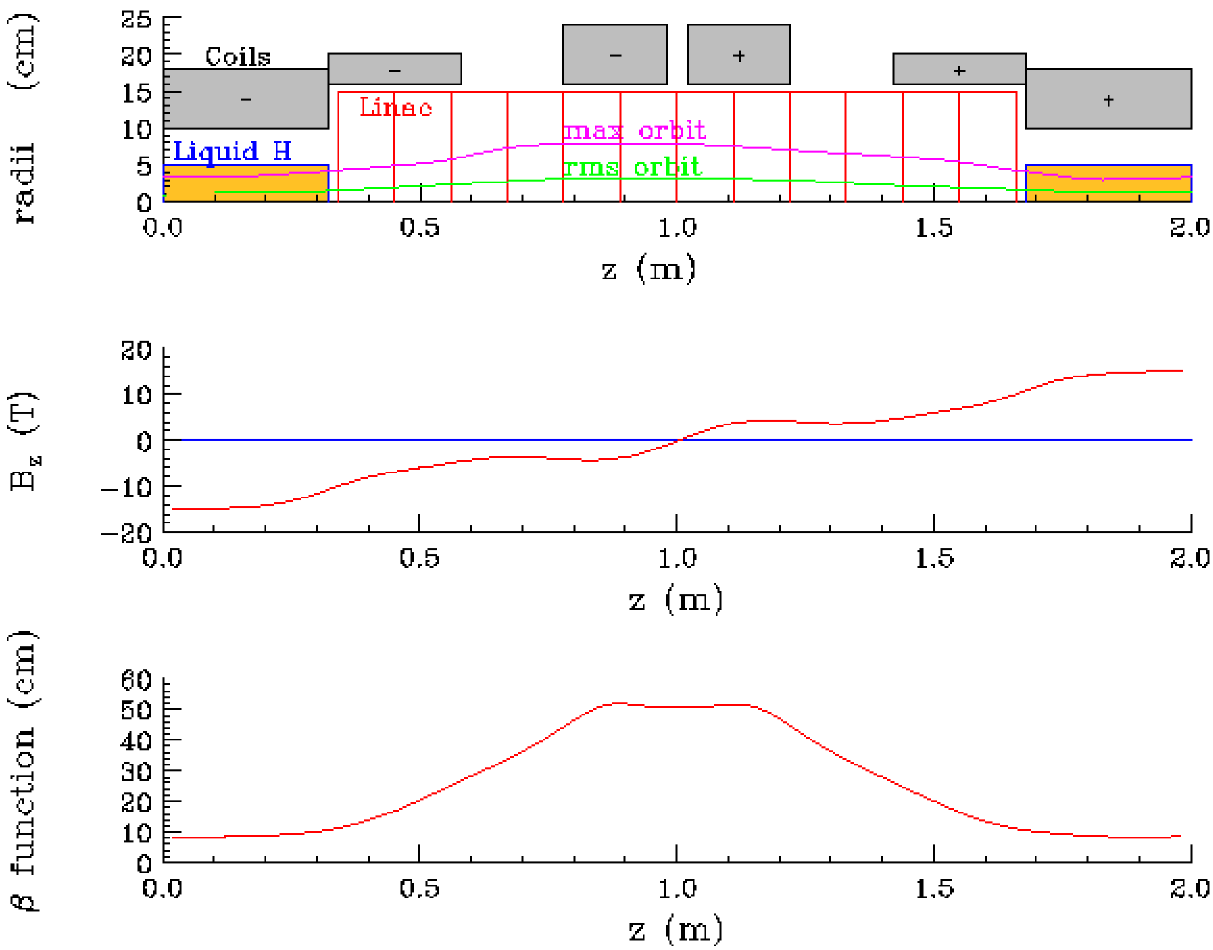
- FY03:

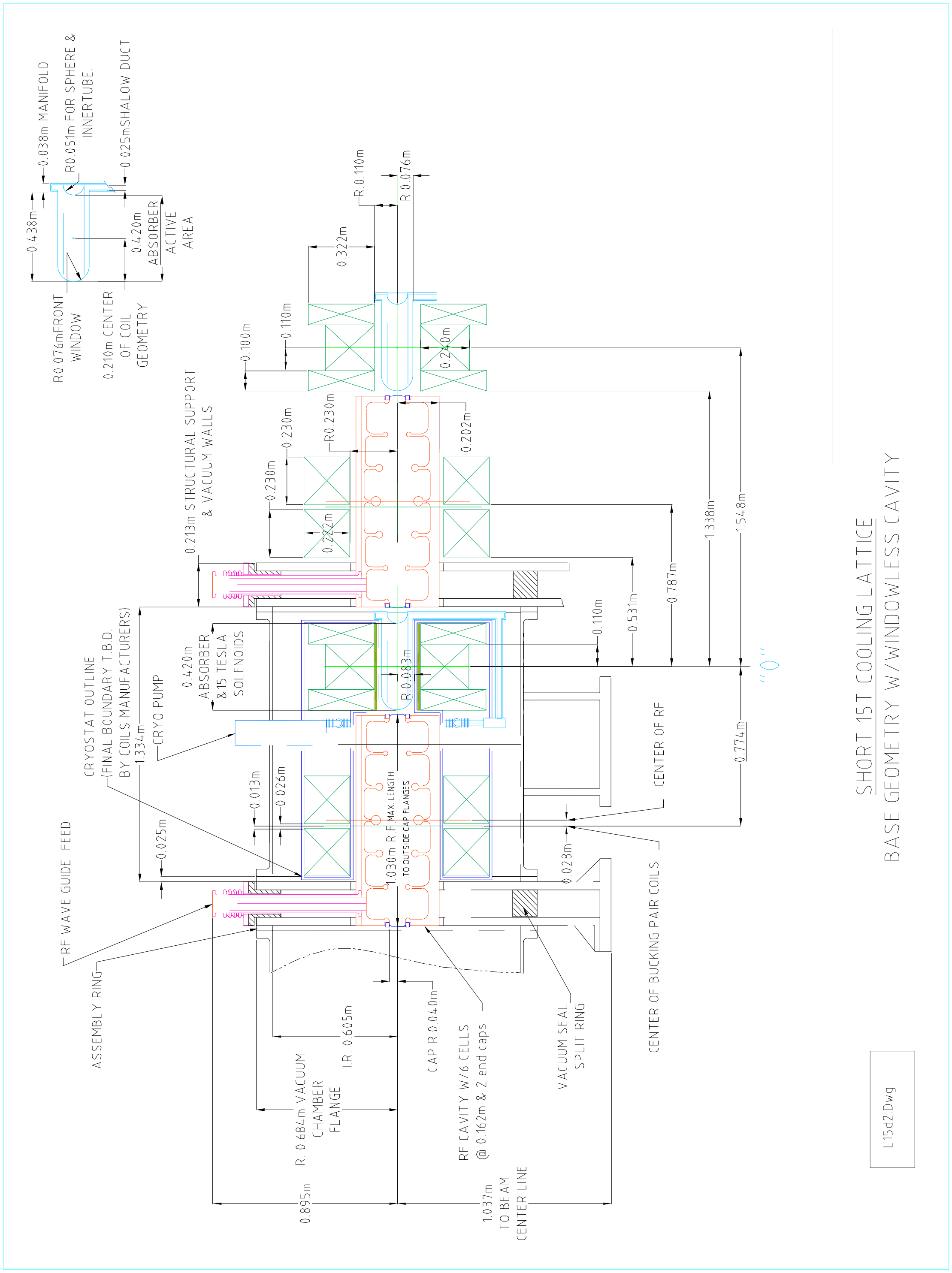
  Complete pion detectors; test with low intensity SEB. (600 hours).

Ionization Cooling

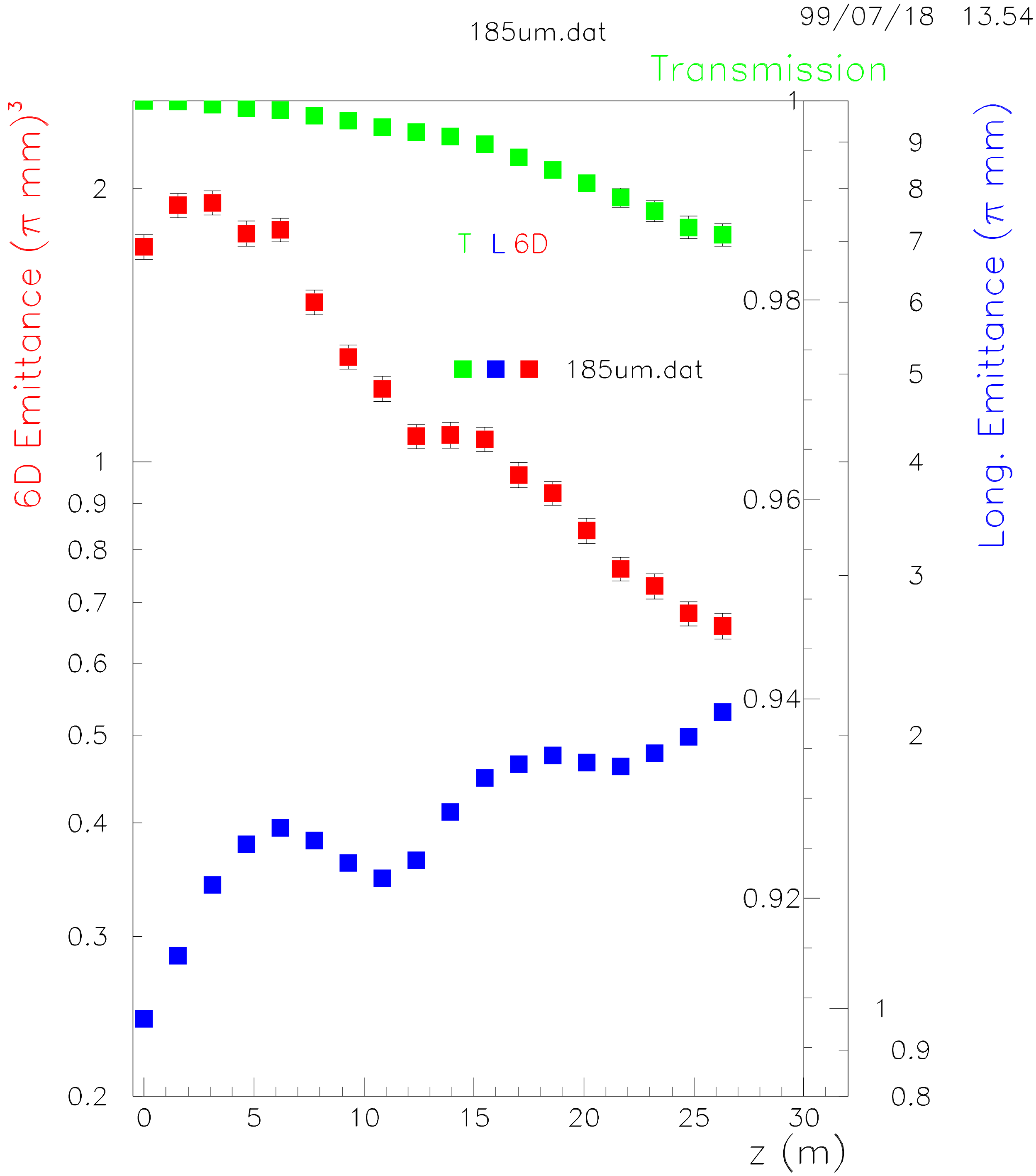
BNL,FNAL,IIT,LBL

Alternating Solenoid



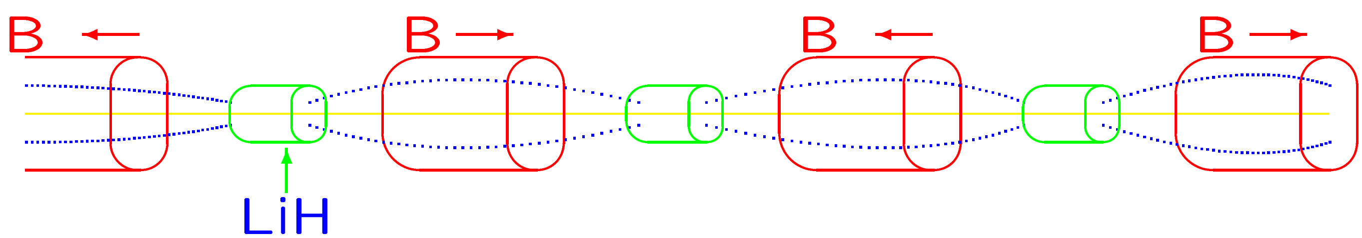

SHORT 15T COOLING LATTICE
BASE GEOMETRY W/WINDOWLESS CAVITY
L15d2.Dwg
0.038m MANIFOLD
R0.051m FOR SPHERE & INNERTUBE.
0.025m SHALOW DUCT
R0.076m FRONT WINDOW
0.210m CENTER OF COIL GEOMETRY
0.420m ABSORBER ACTIVE AREA
0.213m STRUCTURAL SUPPORT & VACUUM WALLS
CRYOSTAT OUTLINE (FINAL BOUNDARY T.B.D. BY COILS MANUFACTURERS)
CRYO PUMP
0.420m ABSORBER & 15 TESLA SOLENOIDS
RF WAVE GUIDE FEED
ASSEMBLY RING
R 0.684m VACUUM CHAMBER FLANGE
I.R. 0.605m
CAP R 0.040m
RF CAVITY W/6 CELLS @ 0.162m & 2 end caps
VACUUM SEAL SPLIT RING
CENTER OF BUCKING PAIR COILS
CENTER OF RF
1.030m R.F. MAX. LENGTH TO OUTSIDE CAP FLANGES
0.895m
1.037m TO BEAM CENTER LINE
"0"

DPGeant simulation, 15T Alt. Sol., 1.548m lattice:

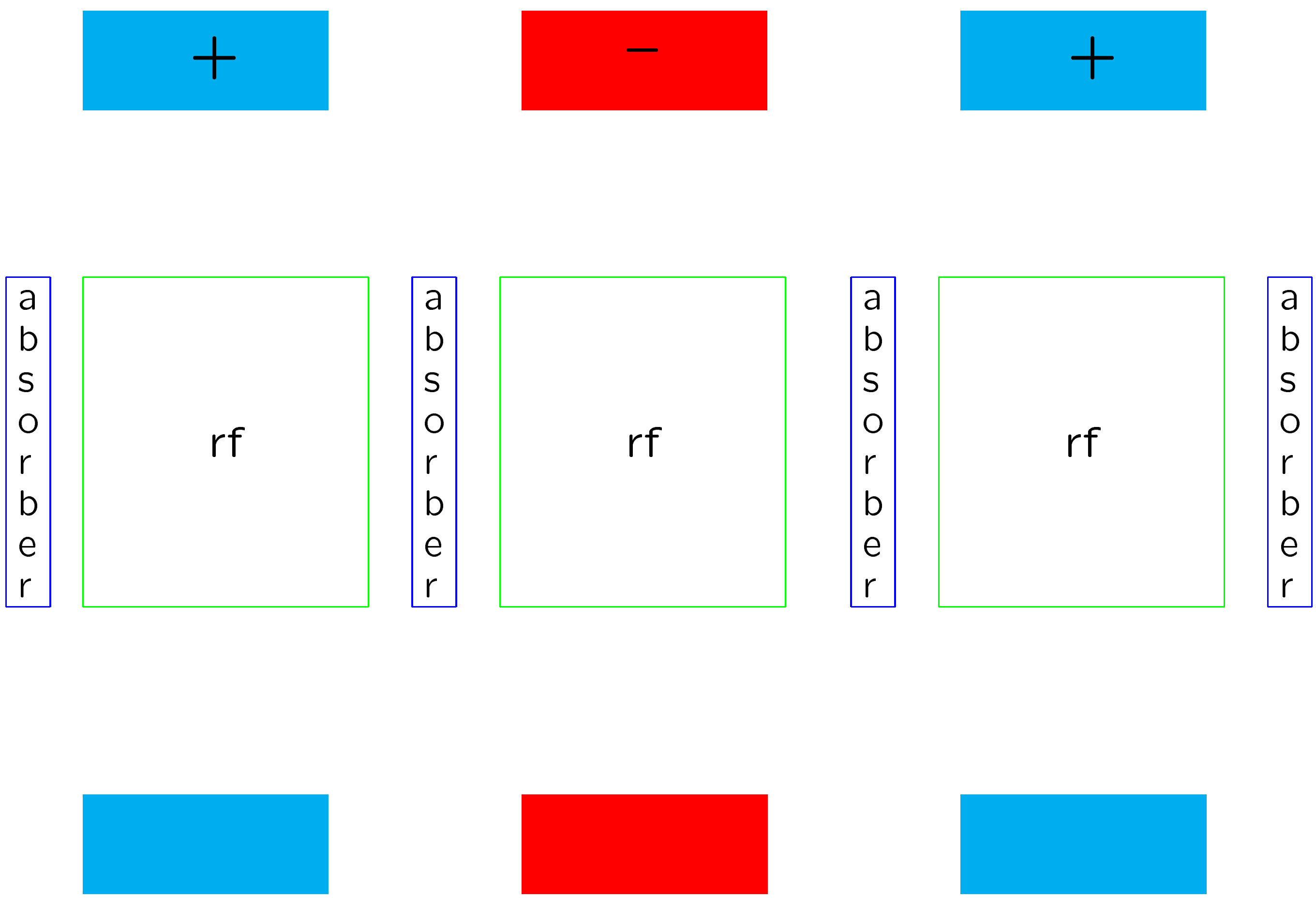


Ionization Cooling

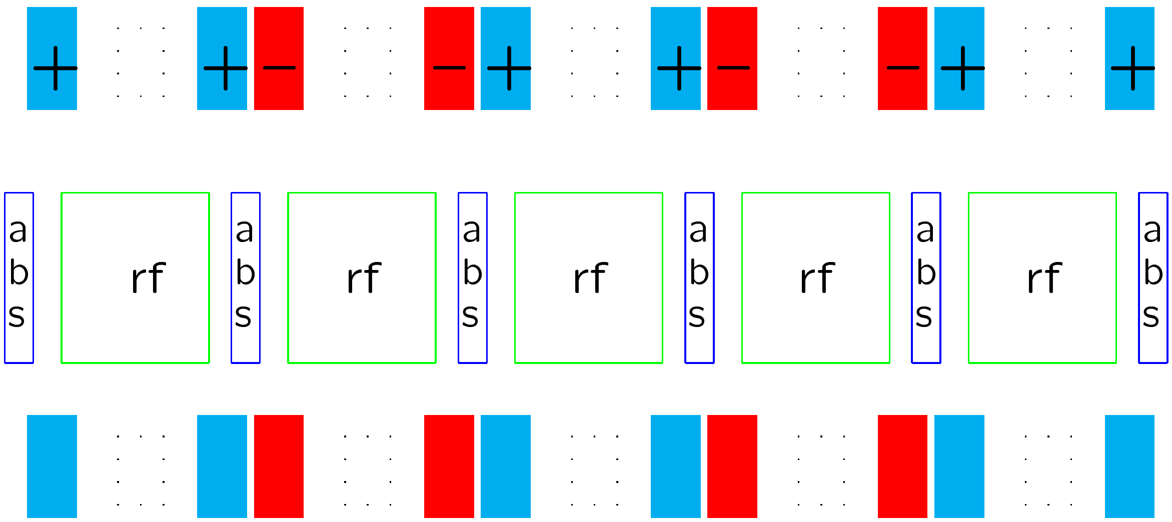
The FOFO Lattice



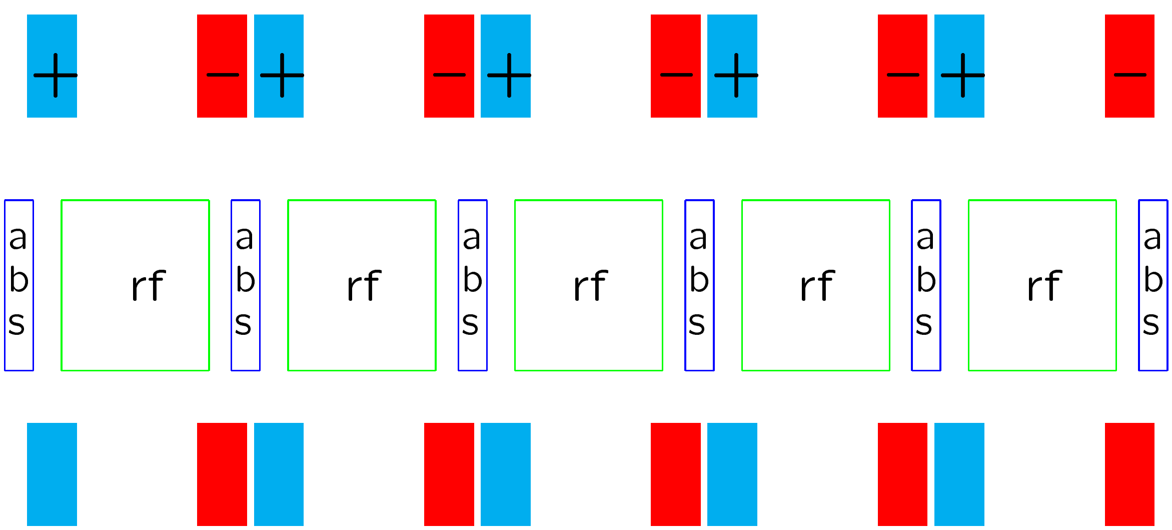
A FOFO Lattice

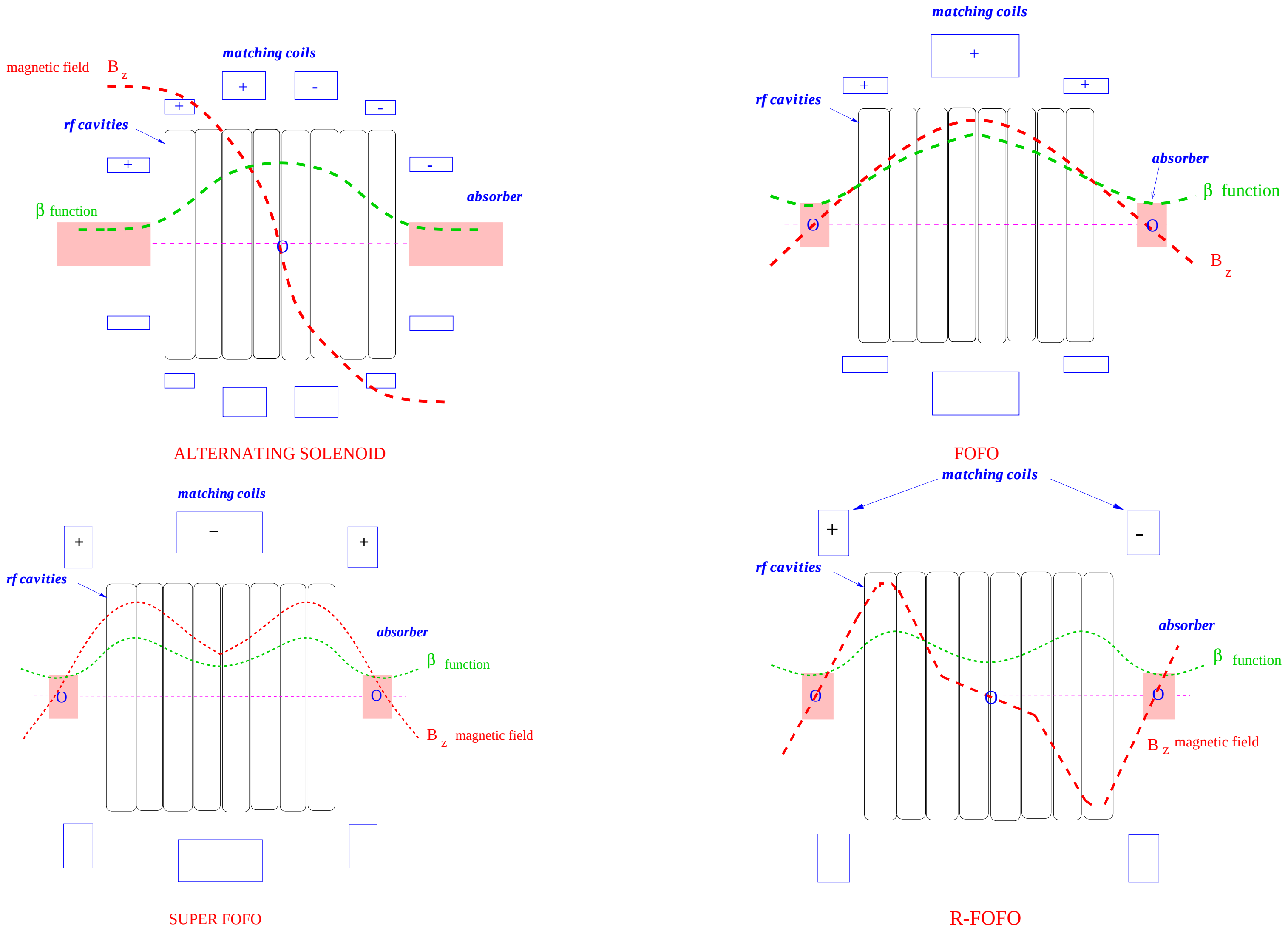


An sFOFO Lattice



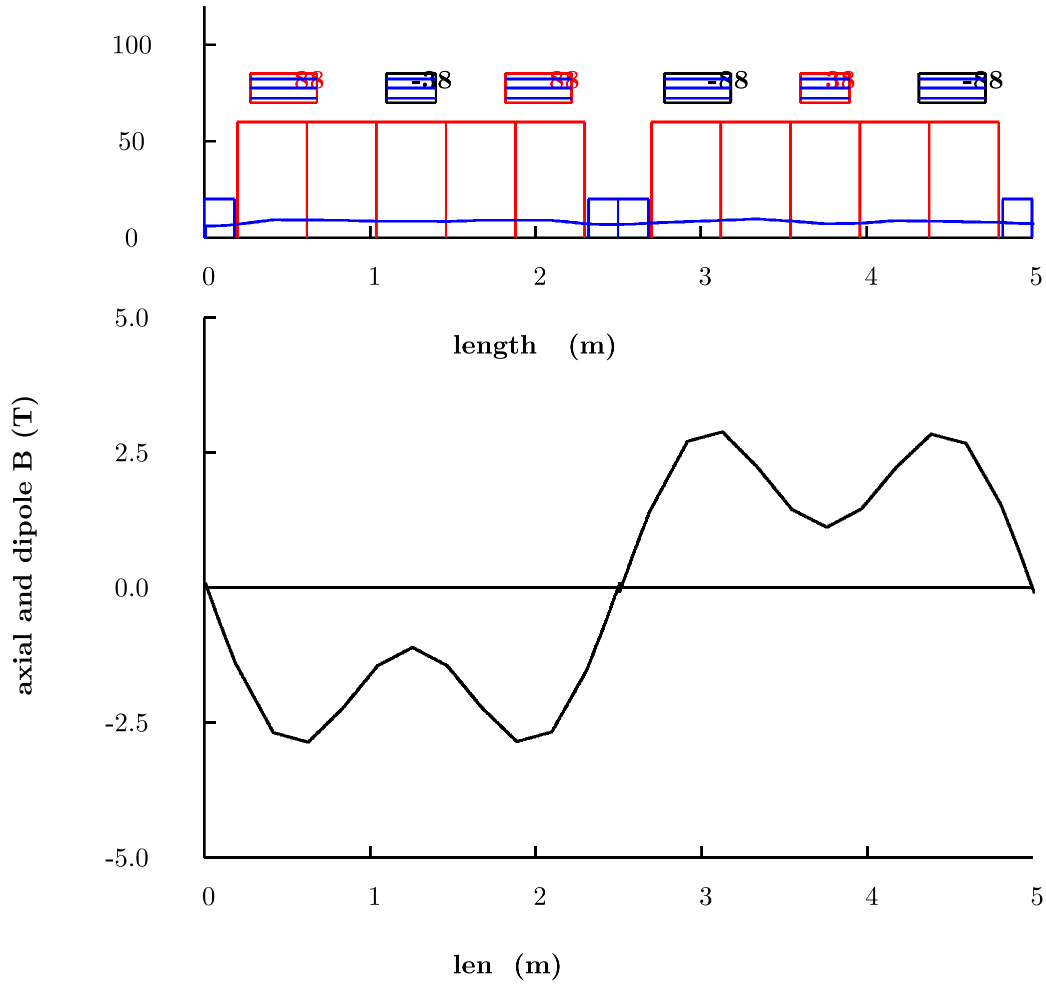
An rFOFO Lattice



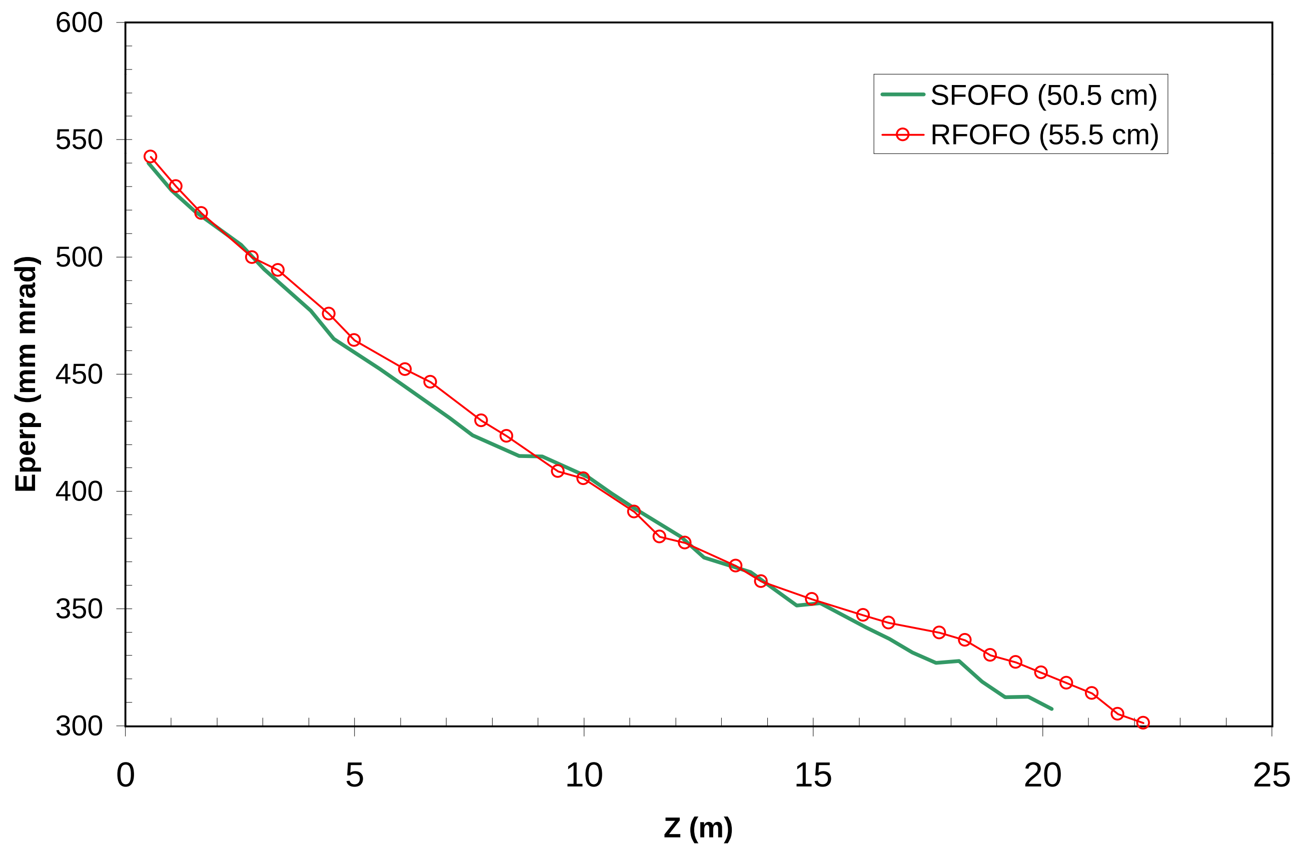


Schematic (not to scale)

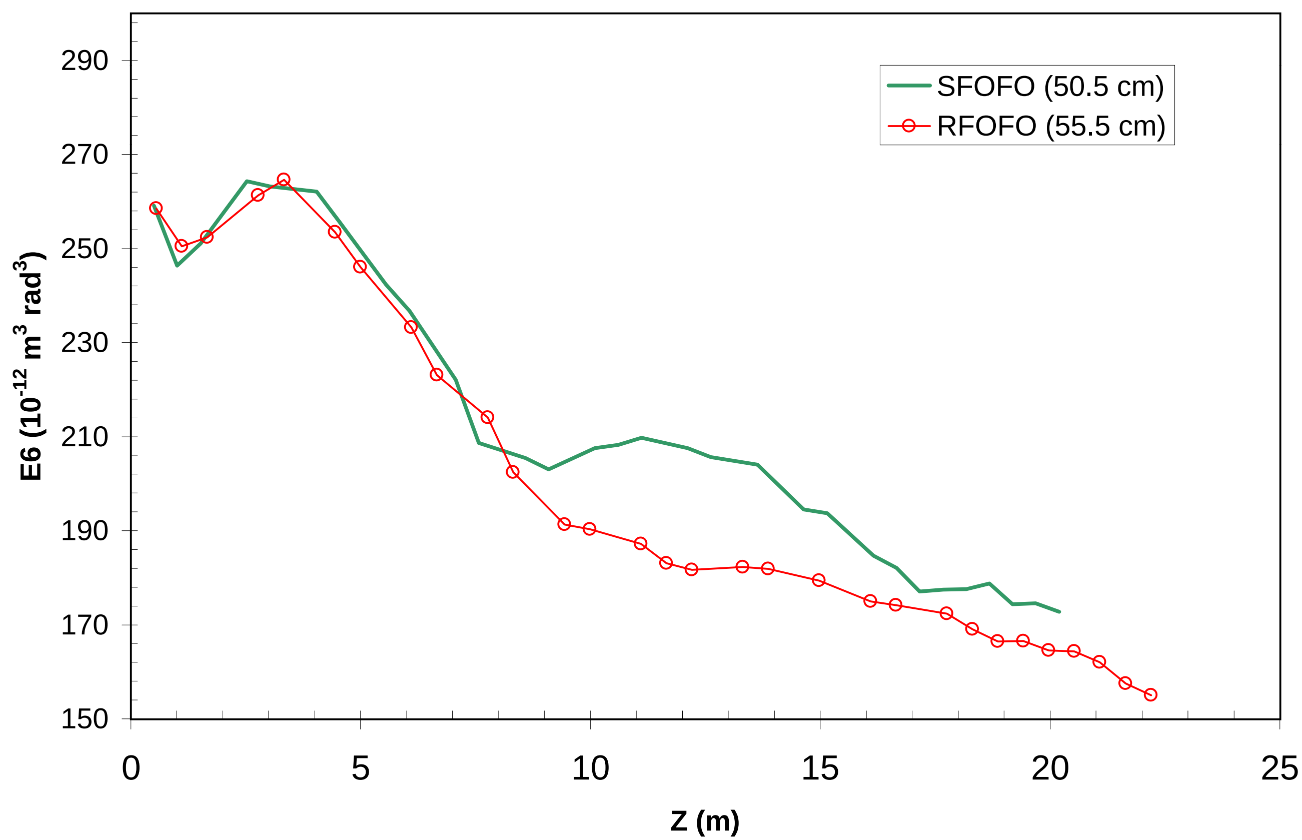
Palmer's sFOFO



- B=2.5T ; L=75m ; p_o=190 MeV/c
- ϵ_T (8000 $\rightarrow$ 3000) π mm-mrad
- ϵ_{6D} ($10^6 \rightarrow 2.5 \times 10^5$) $\times 10^{-12}$ (π m-rad)^3
- rf frequency 175 MHz



Transverse emittance as a function of distance for the SFOFO and stretched RFOFO lattices. Peak field is roughly 10 T, and central beam momentum is 125 MeV/c. There are no beam correlations.

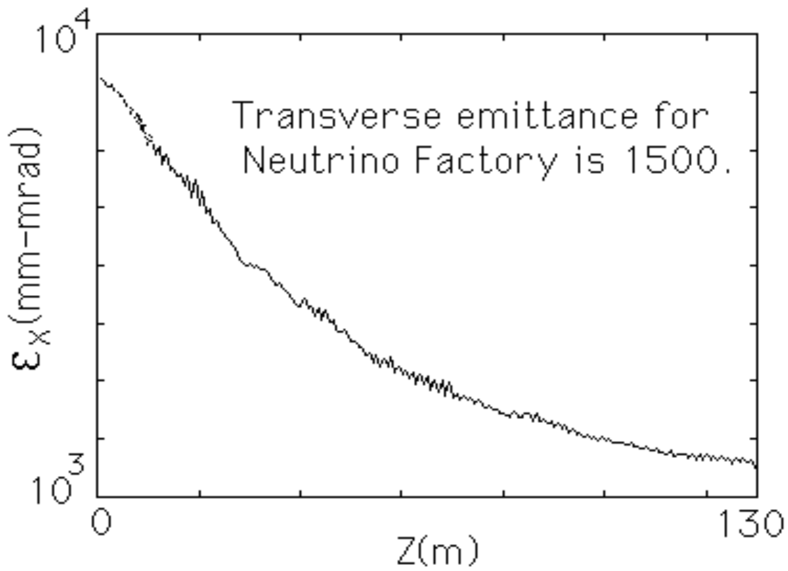


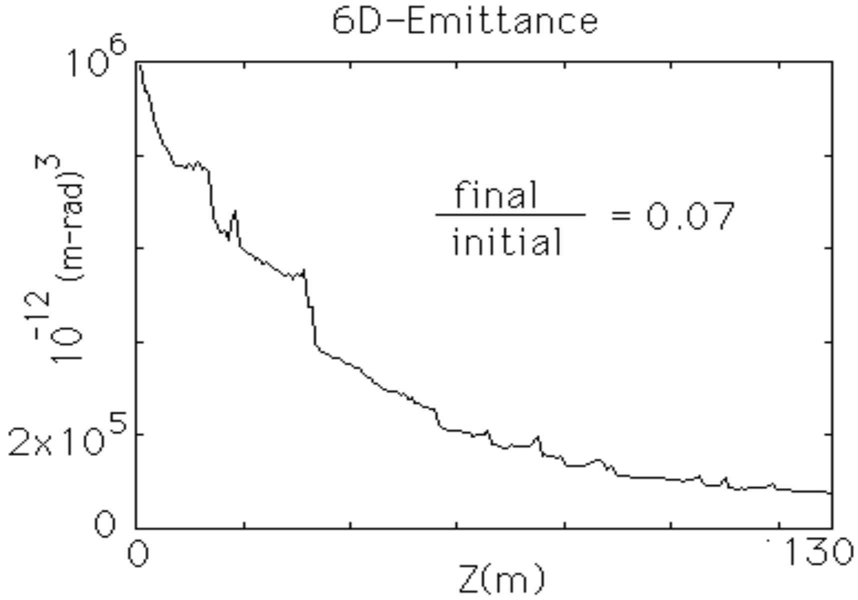
Full 6D emittance as a function of distance for the SFOFO and stretched RFOFO lattices. Peak field is roughly 10 T, and central beam momentum is 125 MeV/c. There are no beam correlations.

Beta function : 30 cm

Final transverse emittance (1500 mm-mrad) needed for Neutrino Factory is obtained at 130m channel.

rms dp/p : 9.4% -> 12.4%
bunch length : 8.15cm -> 12.6 cm
particle loss : 2% at 130m channel





Ionization Cooling Simulation Summary

Alt. Sol

- B=15T ; L=25m ; p_o=187 MeV/c
- ϵ_T (1500 $\rightarrow$ 650) π mm-mrad
- ϵ_{6D} (2000 $\rightarrow$ 700) $\times$ 10^{-12} (π m-rad)^3
- rf frequency 805 MHz

rFOFO

- B=10T ; L=22m ; p_o=125 MeV/c
- ϵ_T (550 $\rightarrow$ 300) π mm-mrad
- ϵ_{6D} (260 $\rightarrow$ 160) $\times$ 10^{-12} (π m-rad)^3
- rf frequency 805 MHz

FOFO

- B=4.4T ; L=130m ; p_o=197 MeV/c
- ϵ_T (8000 $\rightarrow$ 1500) π mm-mrad
- ϵ_{6D} (10^6 $\rightarrow$ 6 $\times$ 10^4) $\times$ 10^{-12} (π m-rad)^3
- rf frequency 175 MHz

Ongoing MUCOOL Activities

1. **Develop the high−gradient RF cavities needed towards the end of the cooling channel.**

2. **Develop an RF power source that can drive these cavities.**

3. **Prepare an RF high−power test setup (Lab G) to test the prototype cavities in a solenoid field.**

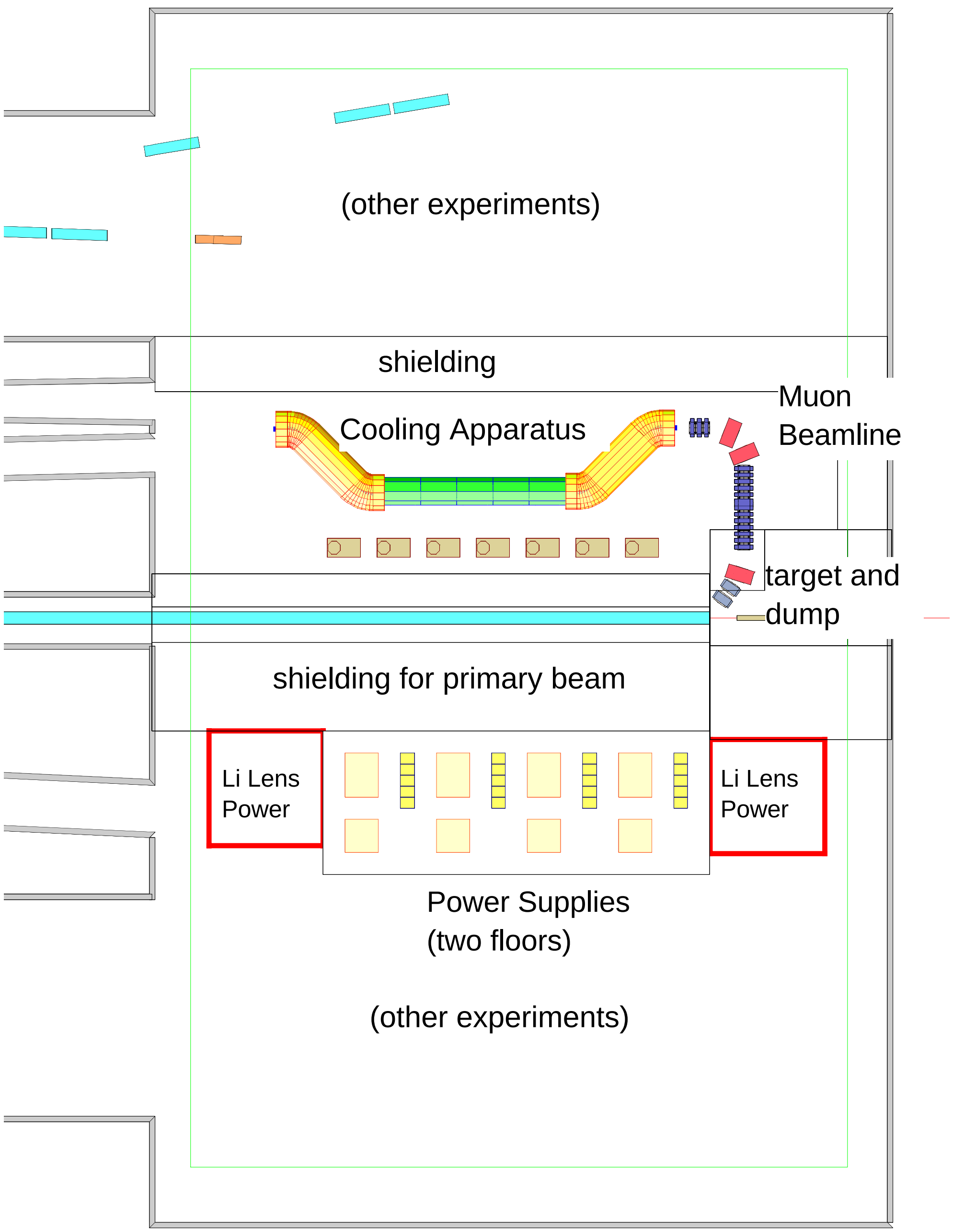
4. **Design a (15 T) alternating solenoid transverse cooling section corresponding to a cooling stage towards the end of the cooling channel. This includes the RF modules, solenoids, and liquid hydrogen absorbers.**

5. **Develop a short (15 cm) liquid lithium lens ... first step towards lenses that could be used at the end of the cooling channel (joint project with FNAL pbar source).**

6. **Design a cooling beam test facility & experiment and prototype instrumentation.**

Muon Cooling Beam Test Facility Layout

T. Kobolarchik

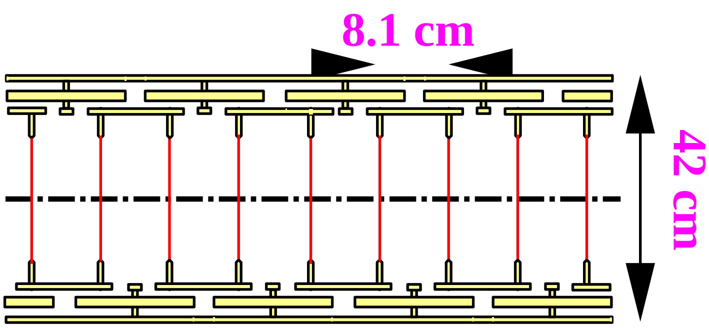


Example: The MCenter Beamline

MUCOOL RF R&D

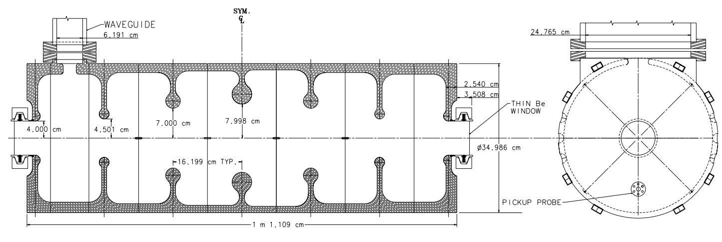
BNL, FNAL, LBNL, Mississippi

Be window cavity design



$\pi/2$ 805 MHz Interleaved Cavity

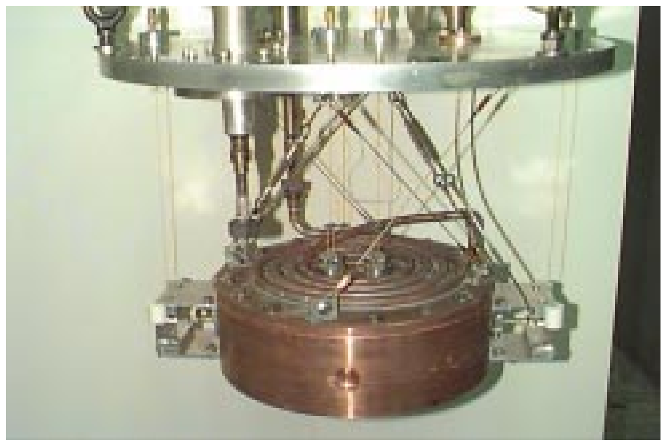
Open cell cavity design



Standing wave linac structure

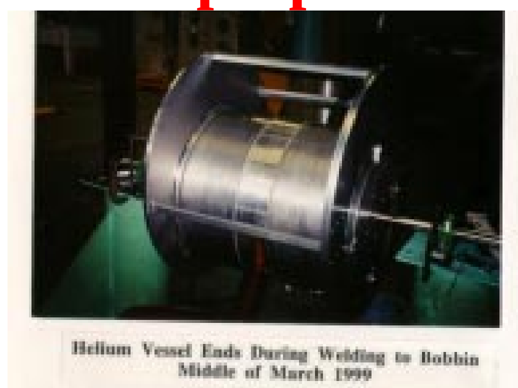
Be window tests

LN_2 Temp Be Properties



Low power cavity tests

Lab G preparation



Power source development

Acceleration

BNL,CERN,FNAL

Scenario #1

- Input emittance: 1500 π mm-mrad
- 175 MHz Linac: 100 MeV $\rightarrow$ 600 MeV
- 350 MHz Linac: 600 MeV $\rightarrow$ 2 GeV
- Recirulating Linac #1: 2 GeV $\rightarrow$ 7.5 GeV
- Recirulating Linac #2: 7.5 GeV $\rightarrow$ 50 GeV

Scenario #2

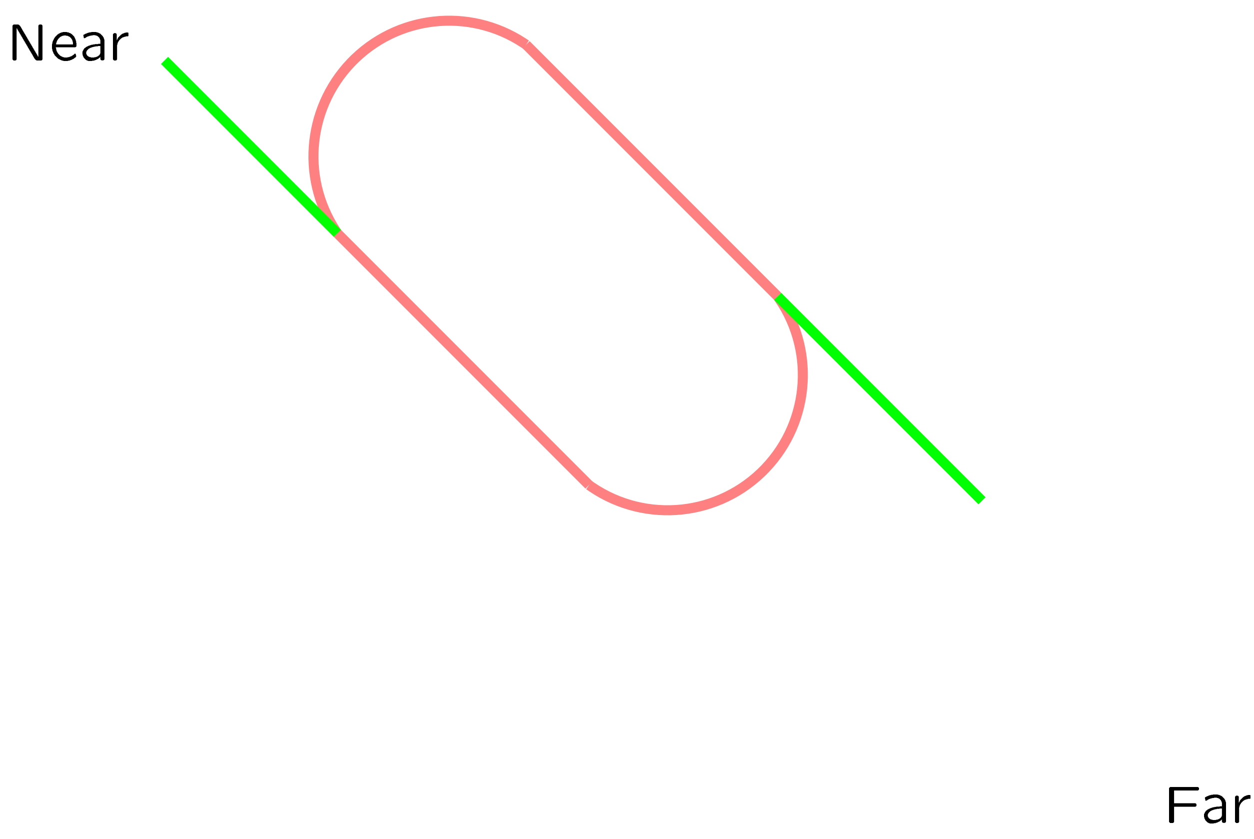
- Input emittance: 3000 π mm-mrad
- Acceleration upto 30 GeV

Storage Rings

CERN,FNAL

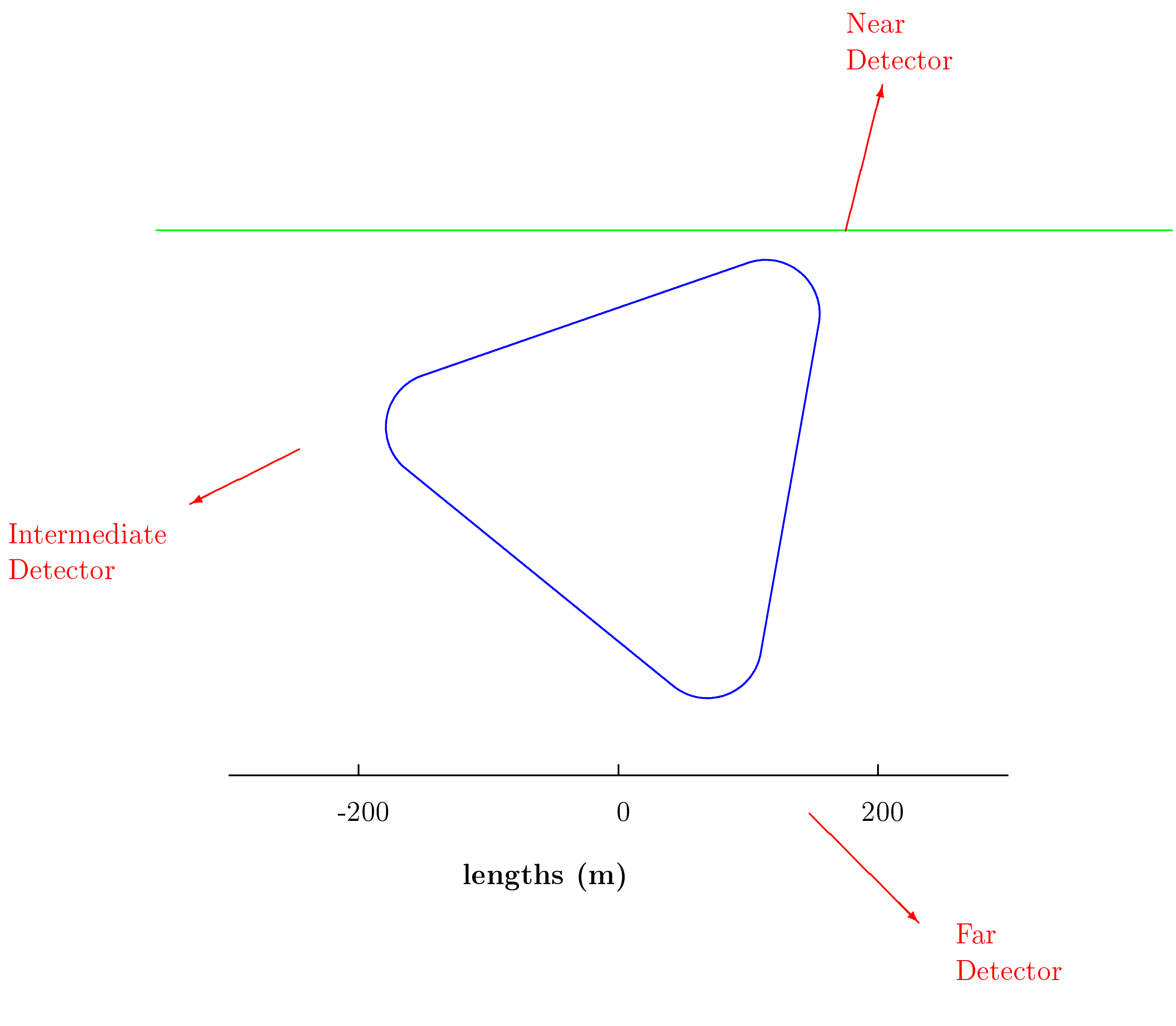
Racetrack

Supports two detectors



Triangular Ring

Supports three detectors



Modified Figure 8

Supports three detectors