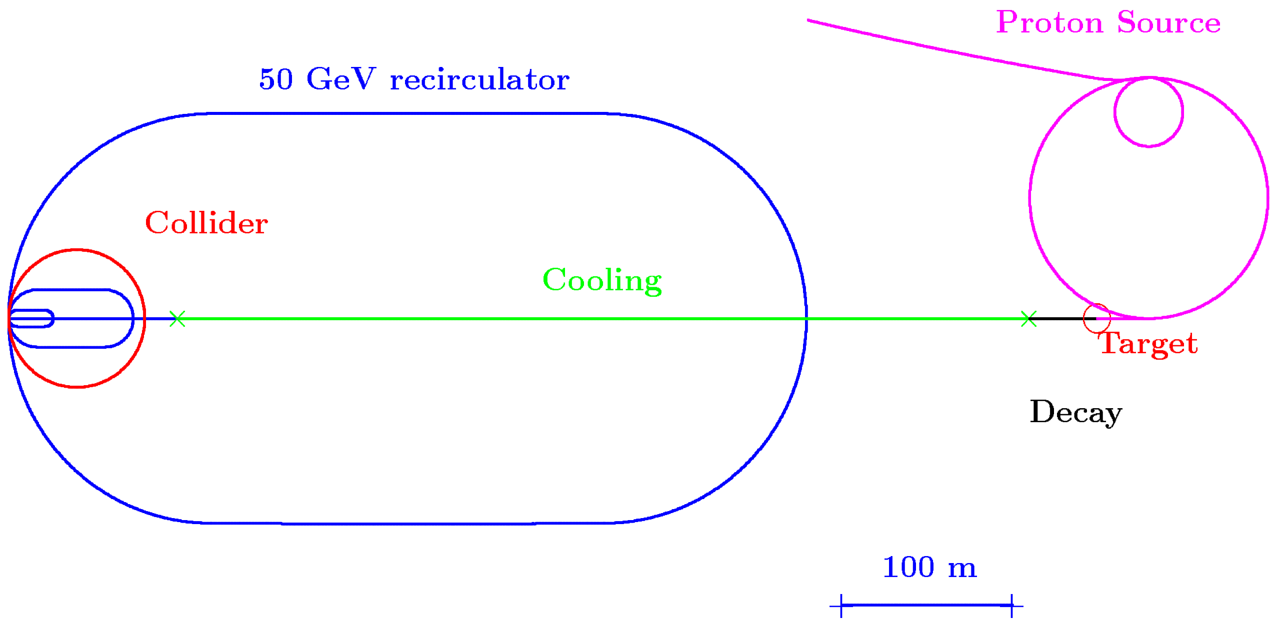
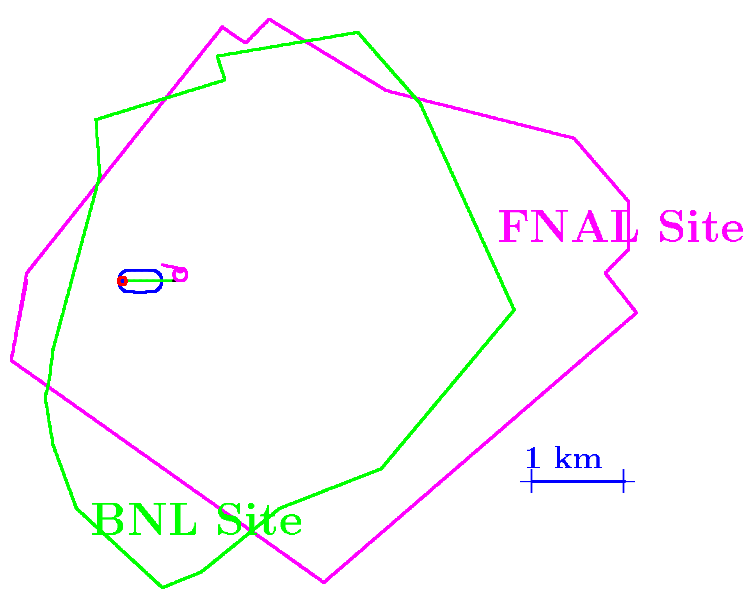
Neutrino factory and muon colliders in the USA

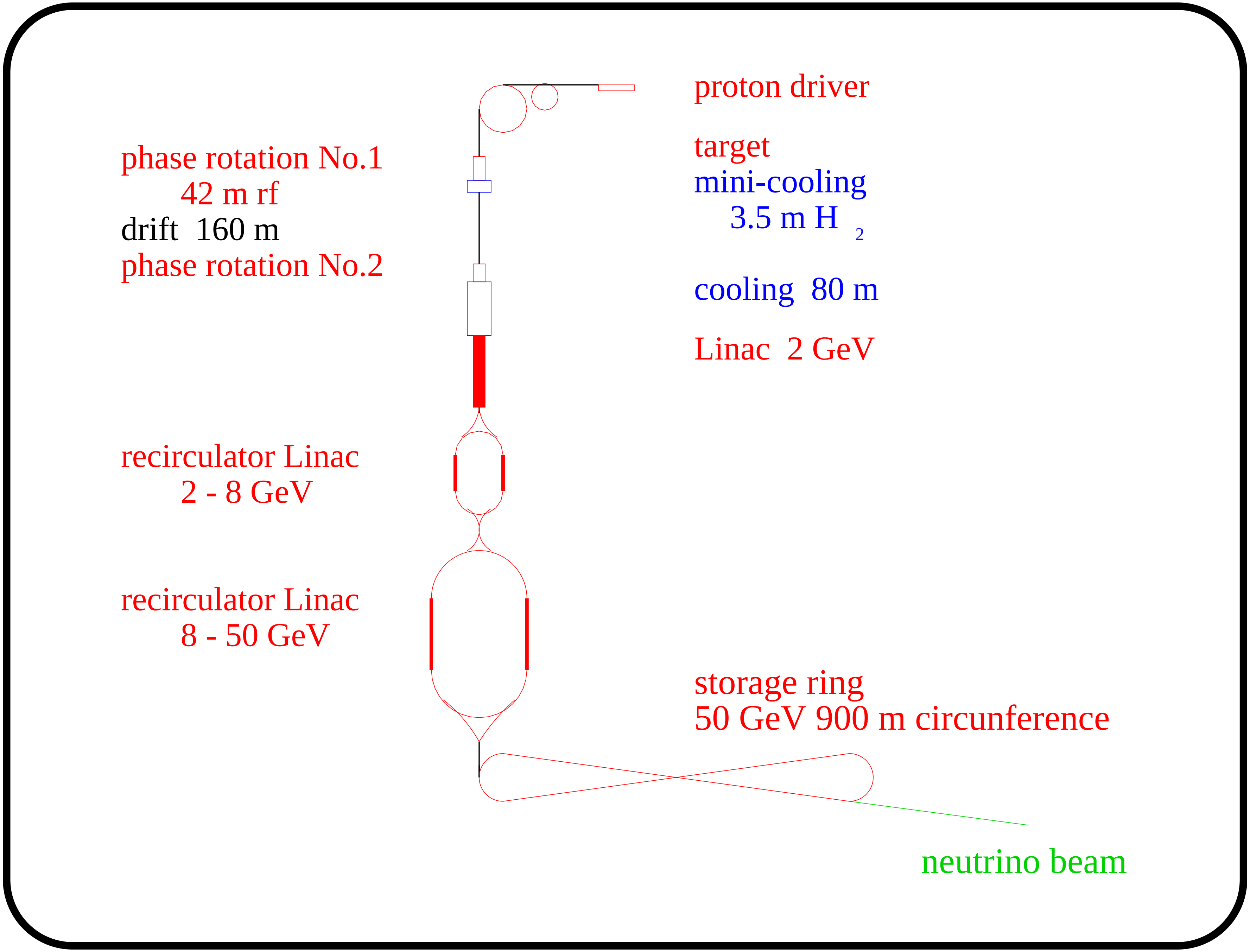
Harold G. Kirk
Brookhaven National Laboratory

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

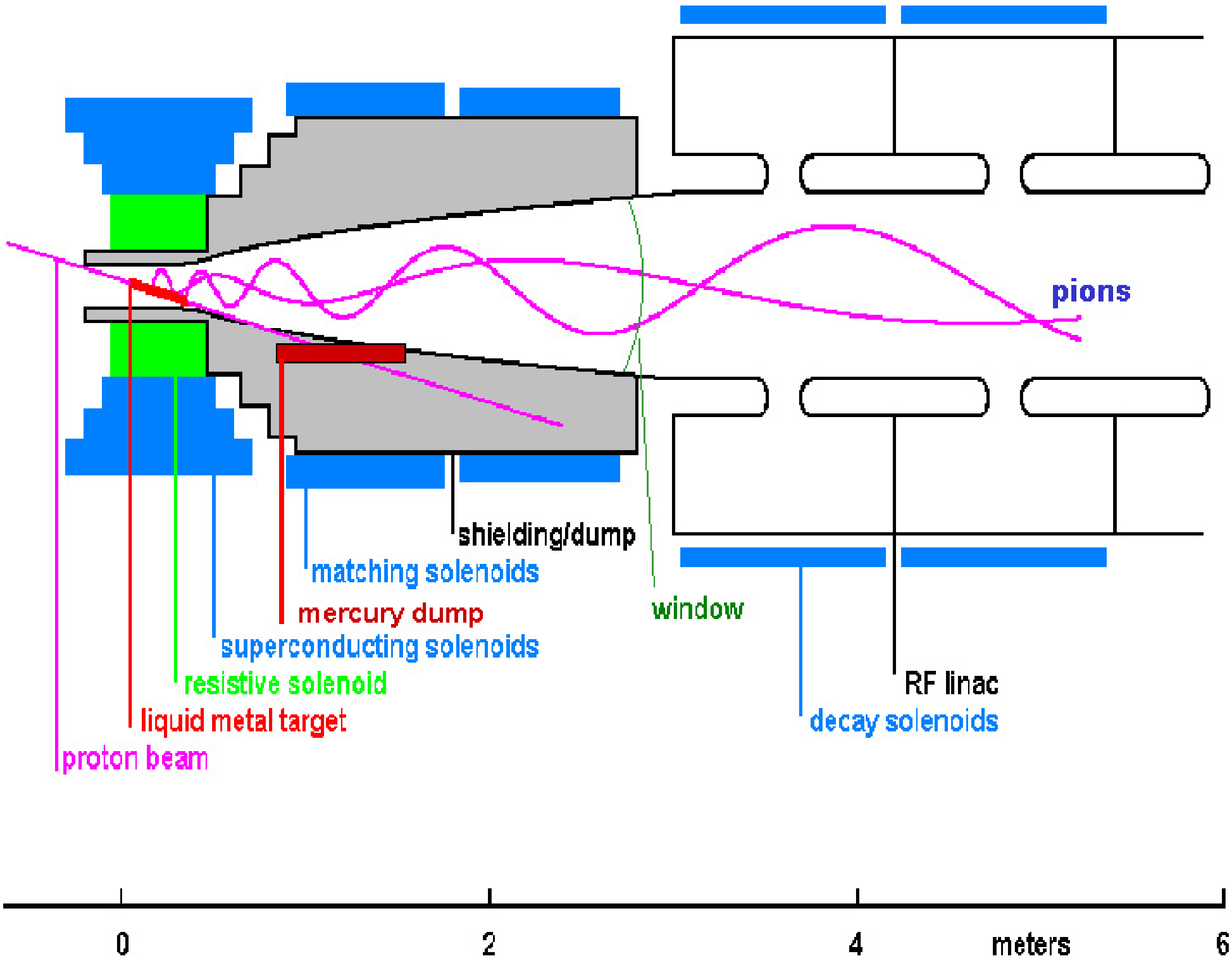
Energy	GEV	24	24	16	16
Power	MW	1	4	1	4
Repetition	Hz	2.5	5	15	15
p's/fill		10^{14}	$2\ 10^{14}$	$2.5\ 10^{13}$	10^{14}
bunches		6	6	4	4
circ.	m	807	807	474	474
spacing	m	135	135	118	118
sigma t	nsec	1	1	1	1

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



- $1.2 \times 10^{14}\ \mu^{\pm}/\text{s}$ 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

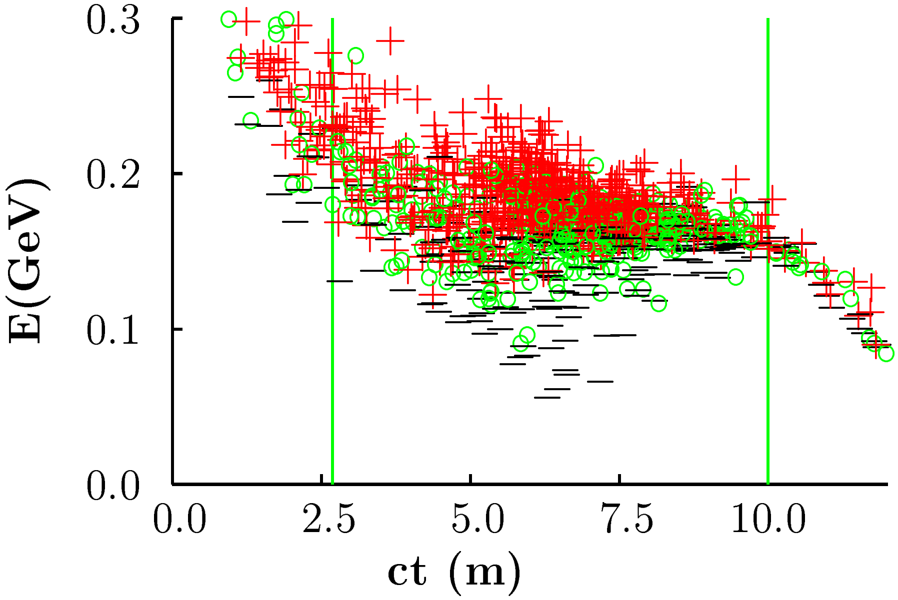
- Shielding
  - 15 cm ID – 24 cm OD
- Inner Coil
  - Resistive coil
  - 4 MW
  - 6 T
  - 24 cm ID – 60 cm OD
- Outer Coils
  - Superconducting
  - 14 T
  - 60 cm ID

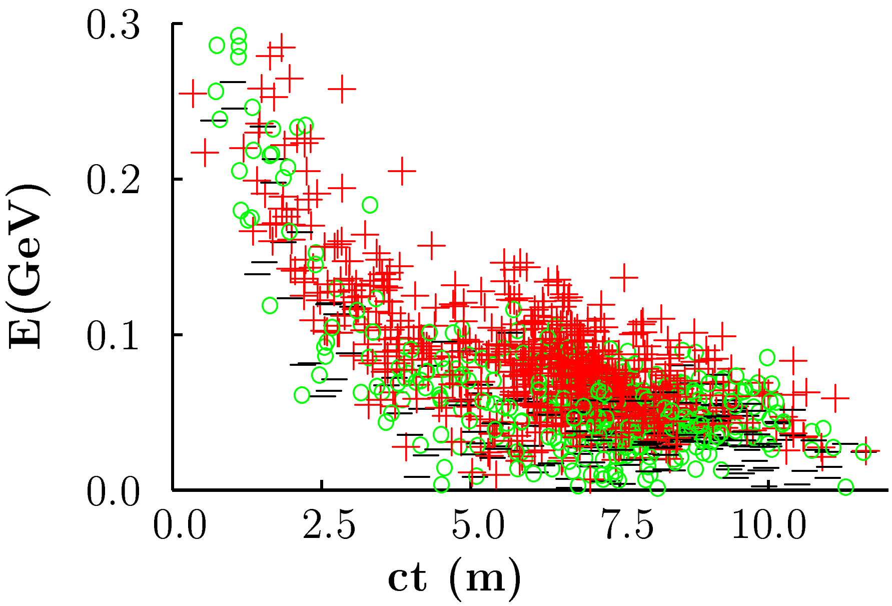
Matching section

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

Phase Rotation

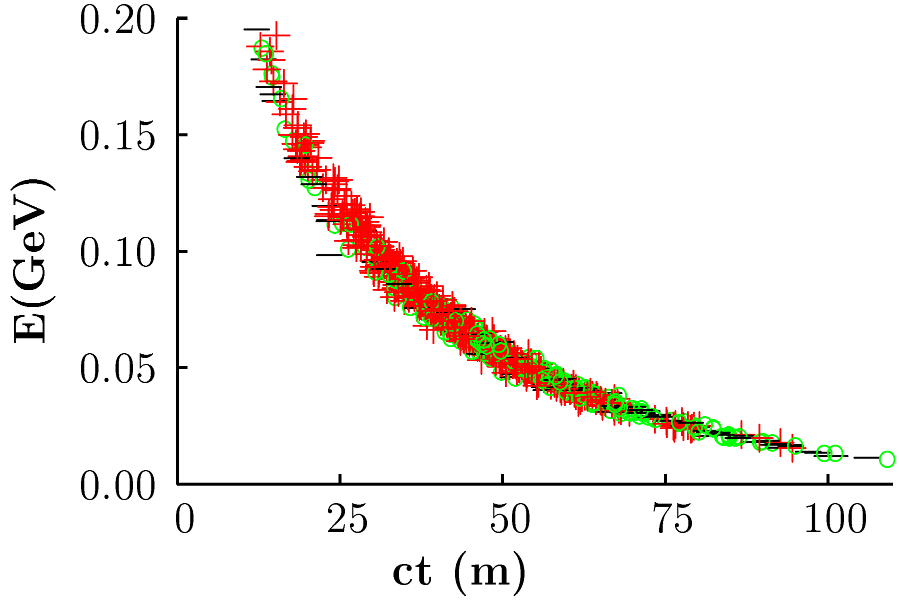
Strategy

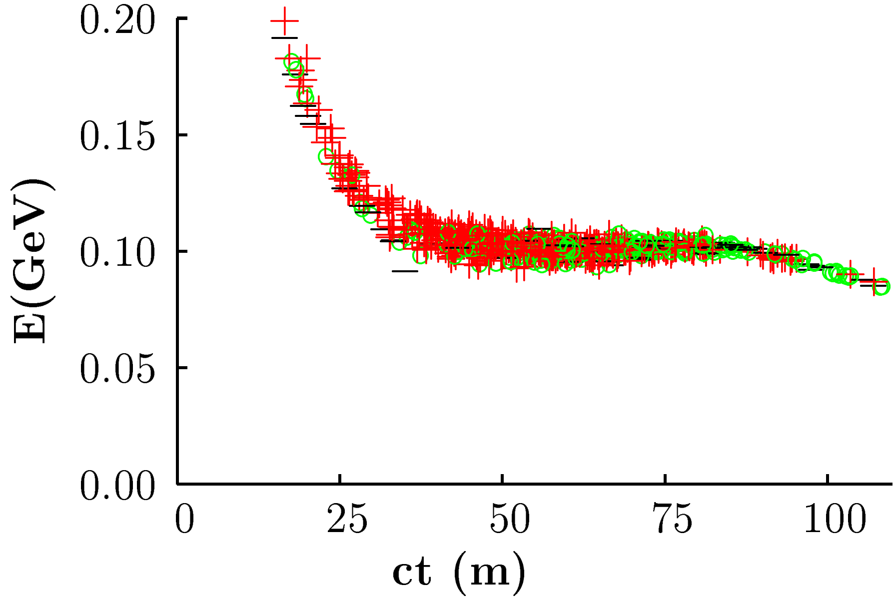




Phase Rotation

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

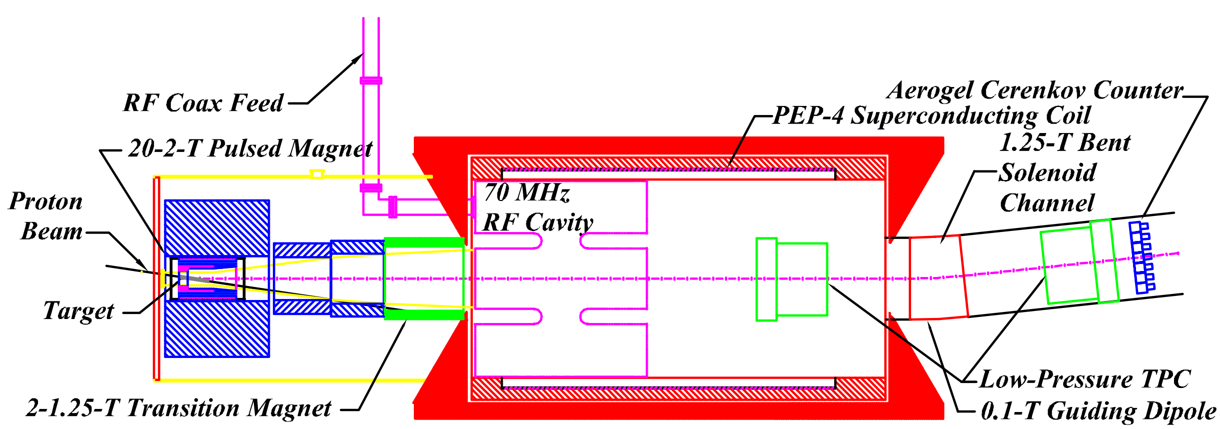
- Yield and spectra of low-energy pions
- Operation of a 20 T SC solenoid surrounding a $\approx$ 4 MW target
- Operation of rf cavity in high radiation environment
- High-gradient pulsed operation of low-frequency rf cavities

The Target Experiment

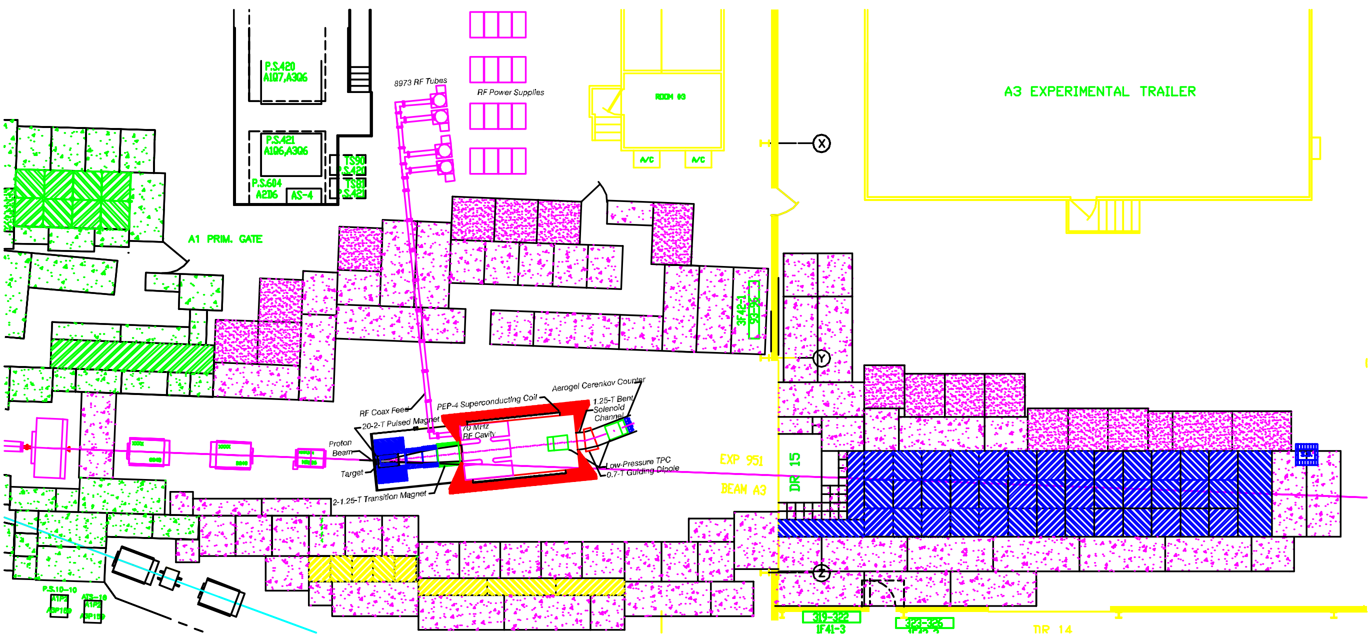
BNL,CERN,LBL,Princeton

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

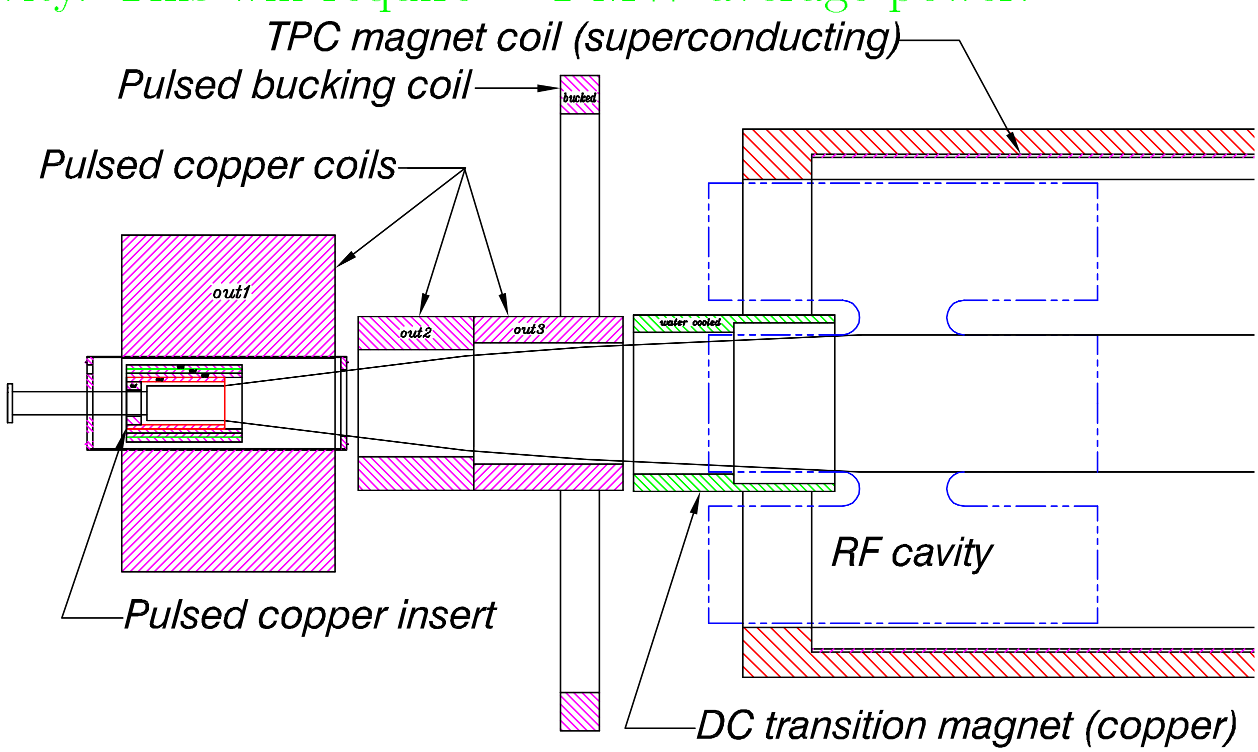


Experiment Layout
in the AGS A3 Line



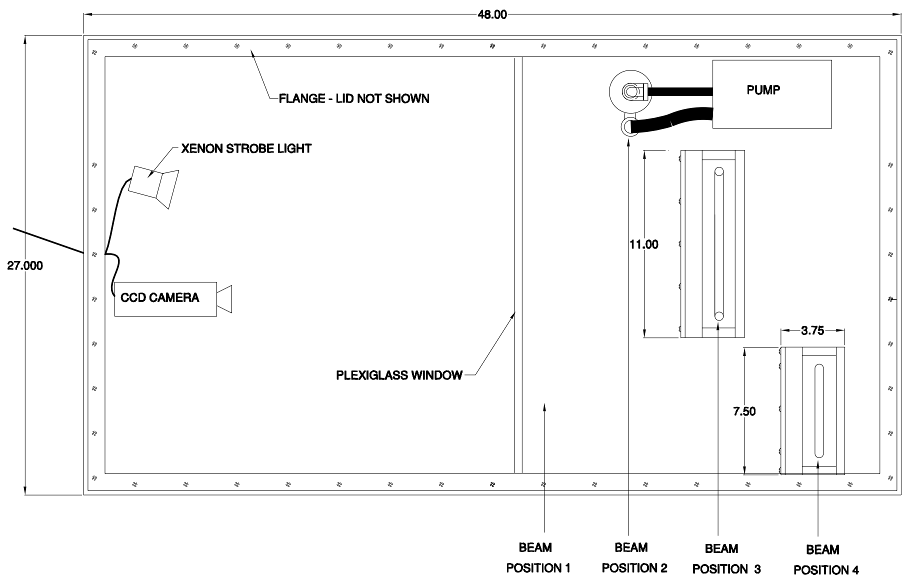
Issues, 4: Pulsed 20-T Magnet

- The copper magnet will be cooled by LN_2, and can be pulsed once every 10 minutes. Pulse duration ≈ 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 ≈ 1 MW average power.

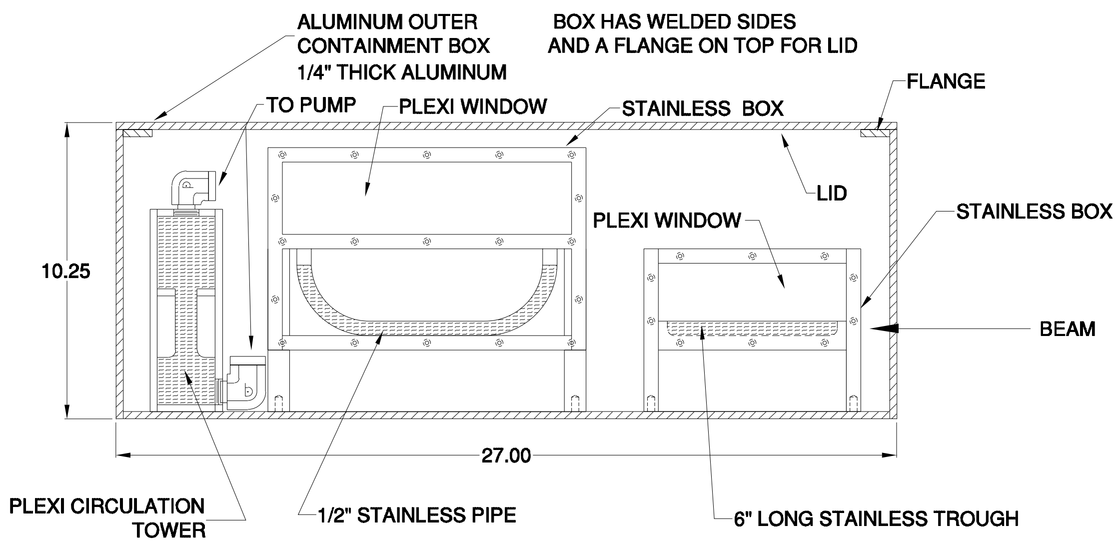


Initial Beam/Liquid Experiment

TOP VIEW



CAMERA VIEW



PIPE AND TROUGH ARE FILLED WITH Ga-Sn EUTECTIC LIQUID METAL

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:

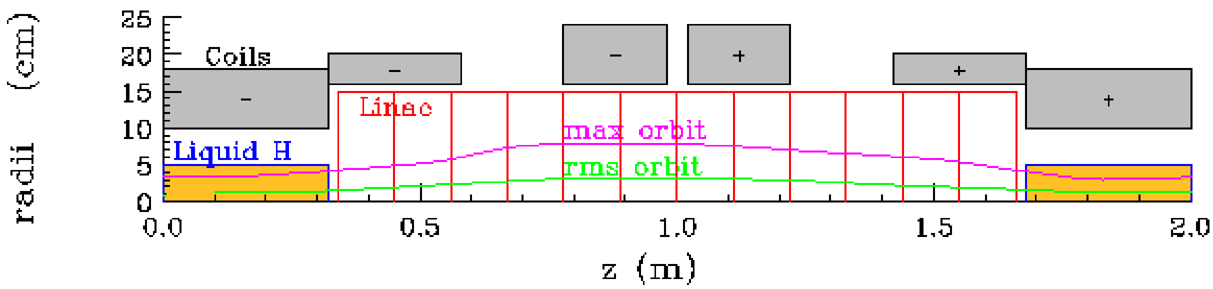
  Complete pion detectors; test with low intensity SEB.

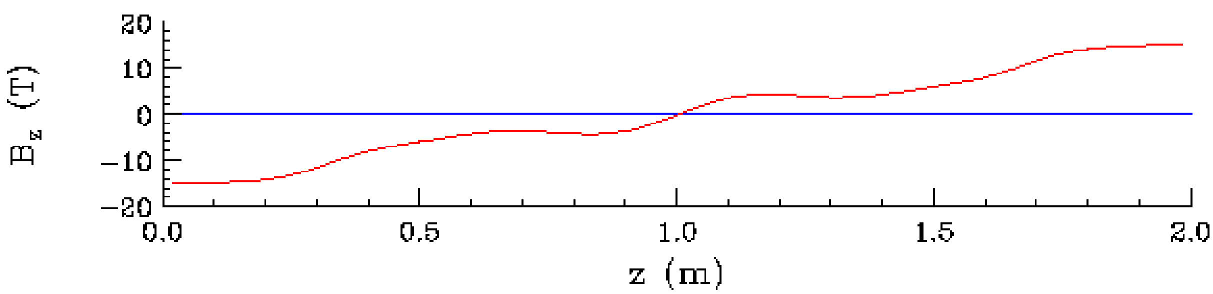
  (600 hours).

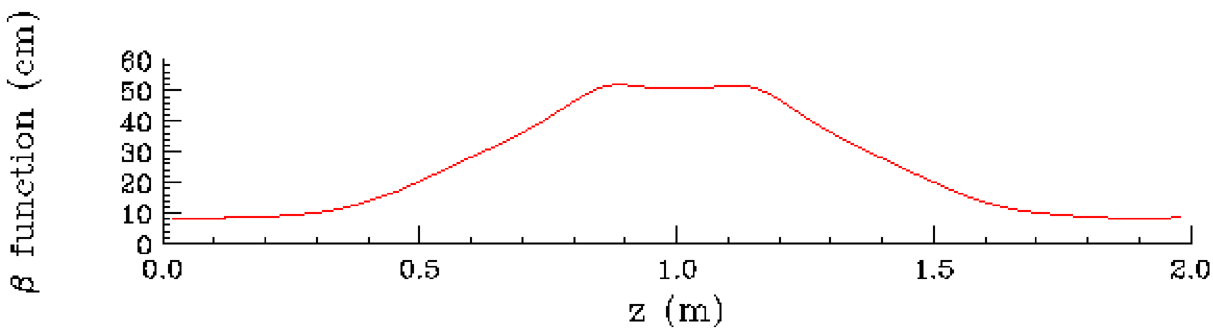
Ionization Cooling

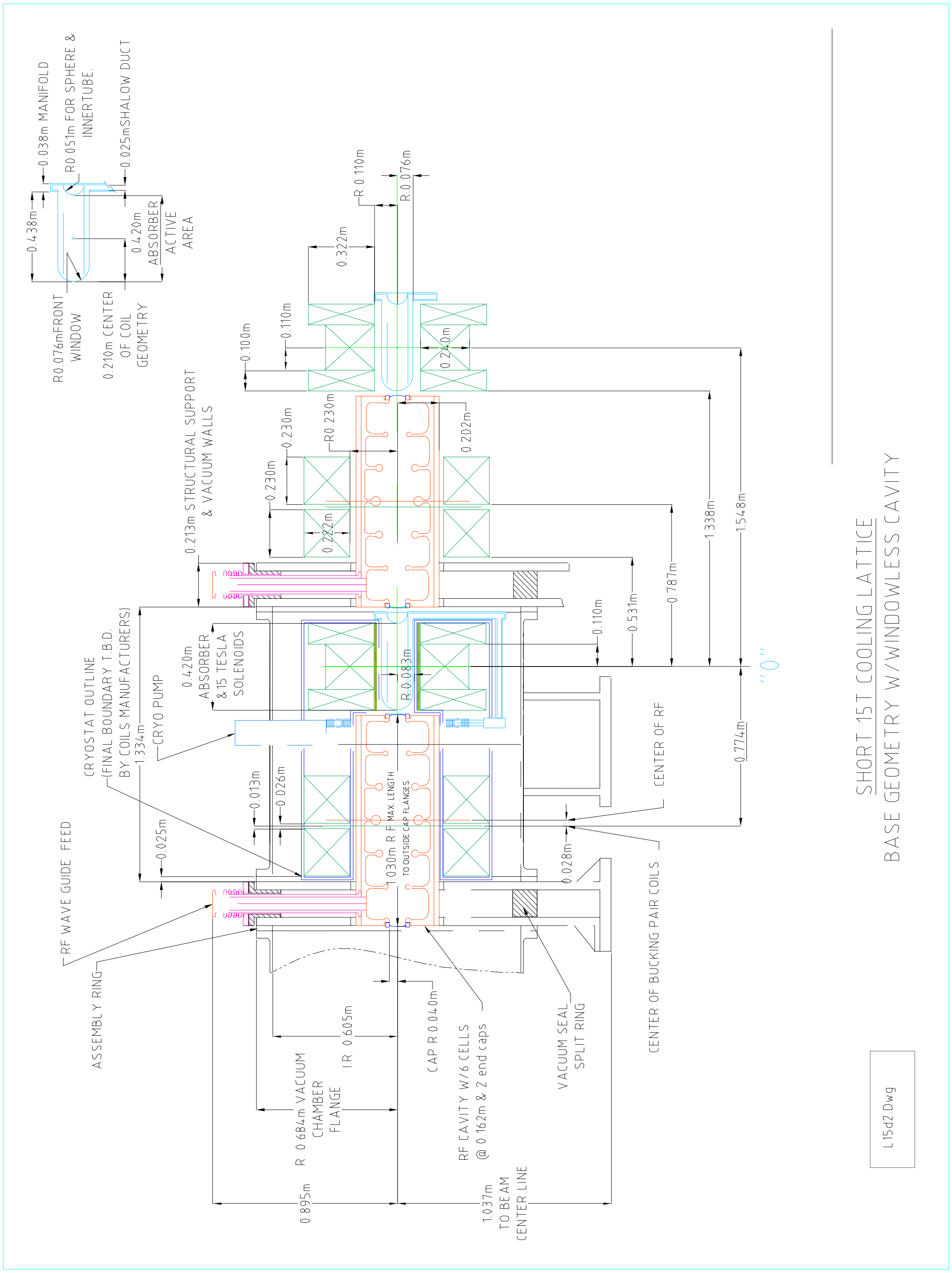
BNL,FNAL,IIT,LBL

Alternating Solenoid

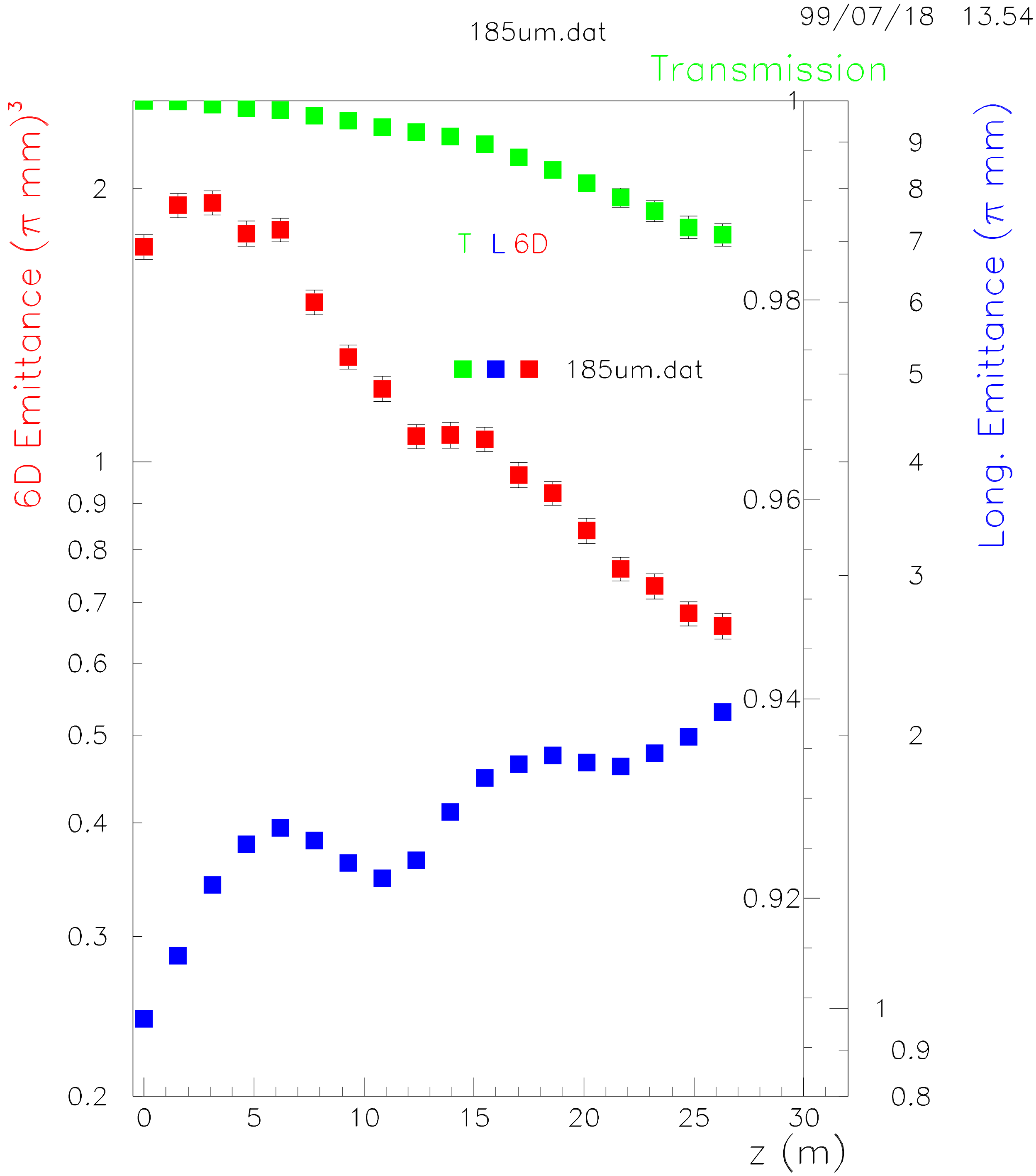






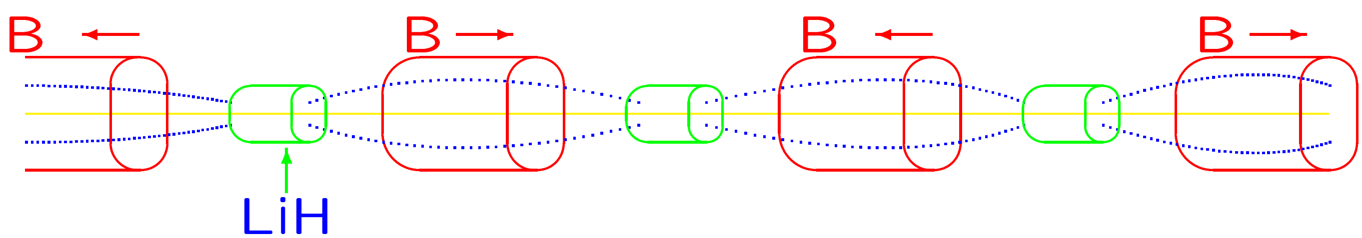

SHORT 15T COOLING LATTICE
BASE GEOMETRY W/WINDOWLESS CAVITY
0.038m MANIFOLD
R0.051m FOR SPHERE & INNERTUBE.
0.025m SHALOW DUCT
0.438m
R0.076m FRONT WINDOW
0.210m CENTER OF COIL GEOMETRY
0.420m ABSORBER ACTIVE AREA
0.213m STRUCTURAL SUPPORT & VACUUM WALLS
CRYOSTAT OUTLINE (FINAL BOUNDARY T.B.D. BY COILS MANUFACTURERS)
1.334m
CRYO PUMP
0.420m ABSORBER & 15 TESLA SOLENOIDS
RF WAVE GUIDE FEED
ASSEMBLY RING
0.025m
0.013m
0.026m
I.R. 0.605m
R 0.684m VACUUM CHAMBER FLANGE
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
0.895m
1.037m TO BEAM CENTER LINE
1.030m R.F. MAX. LENGTH TO OUTSIDE CAP FLANGES
R 0.110m
R 0.076m
0.322m
0.110m
0.100m
0.230m
0.230m
R0.230m
0.202m
0.222m
0.240m
R 0.083m
0.028m
0.110m
0.531m
0.787m
1.338m
1.548m
0.774m
"0"
L15d2.Dwg

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

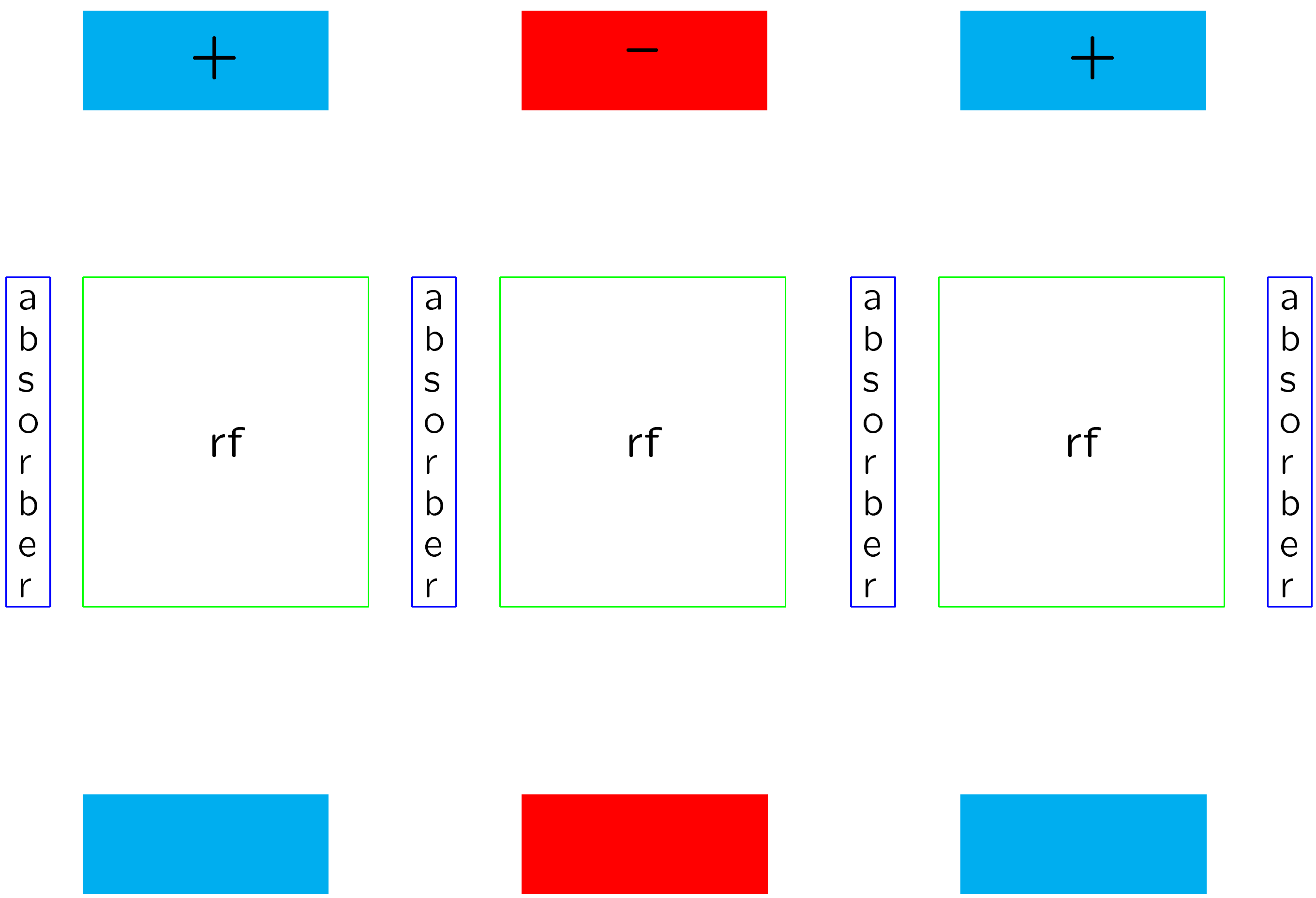


Ionization Cooling

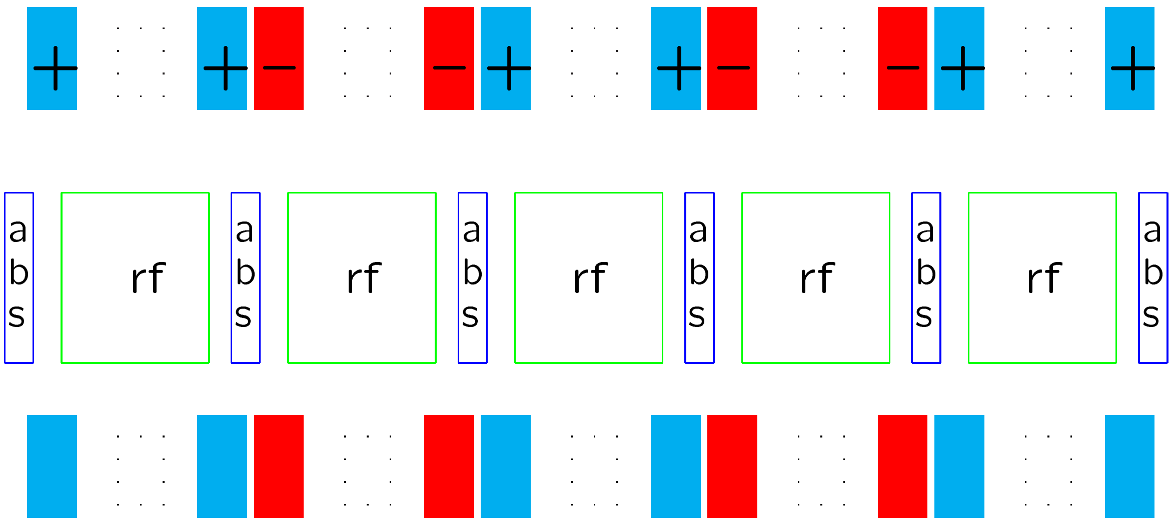
The FOFO Lattice



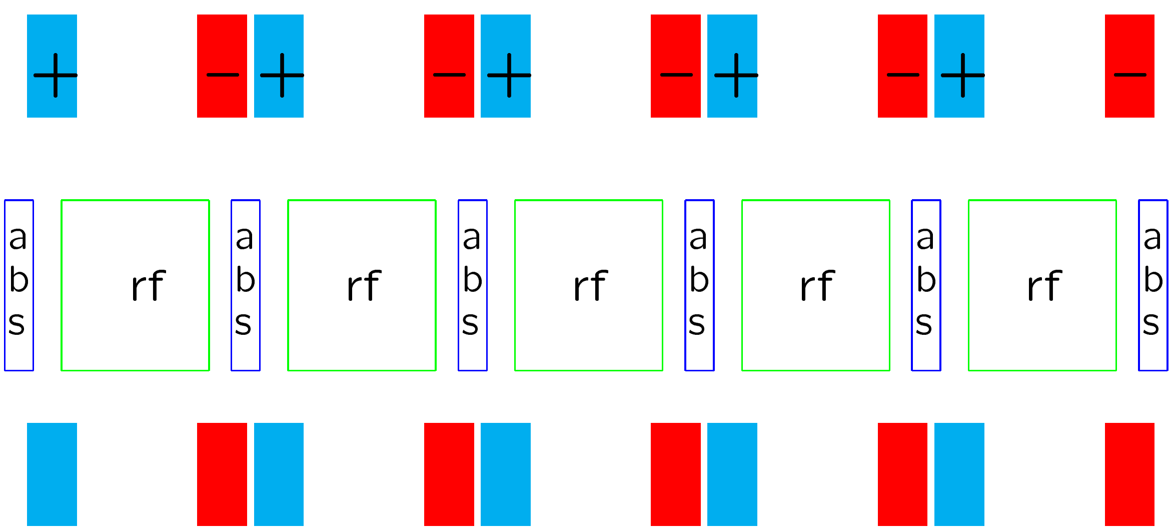
A FOFO Lattice

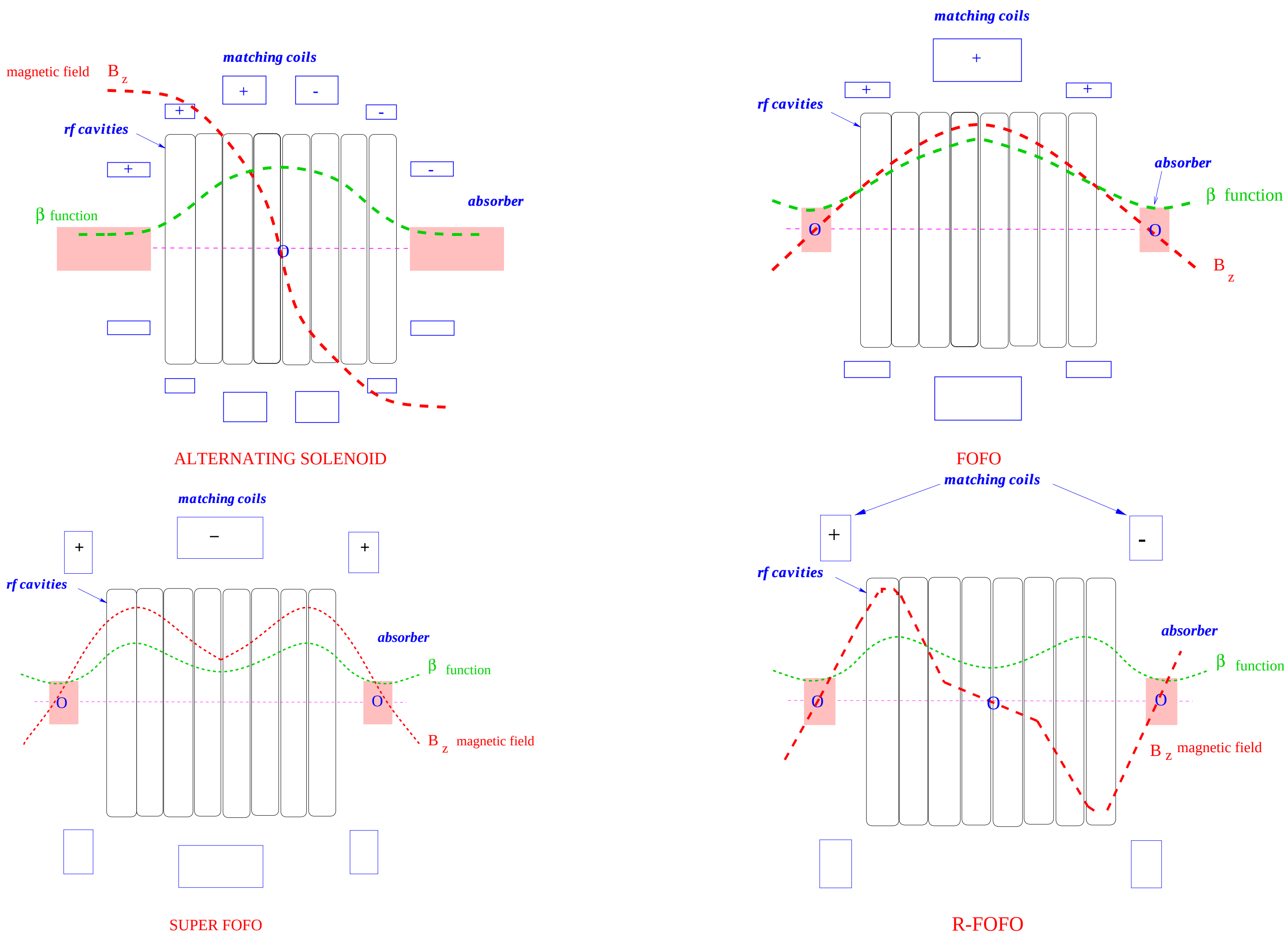


An sFOFO Lattice



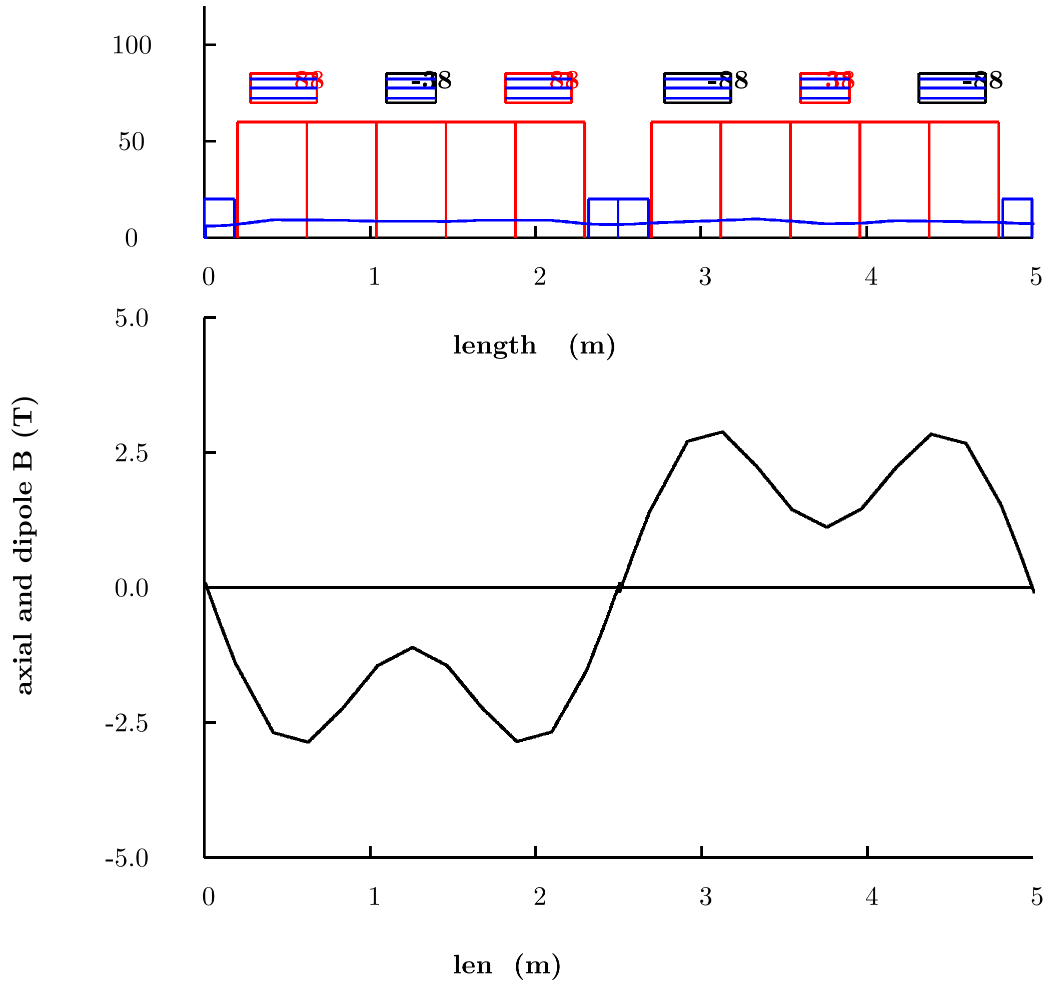
An rFOFO Lattice



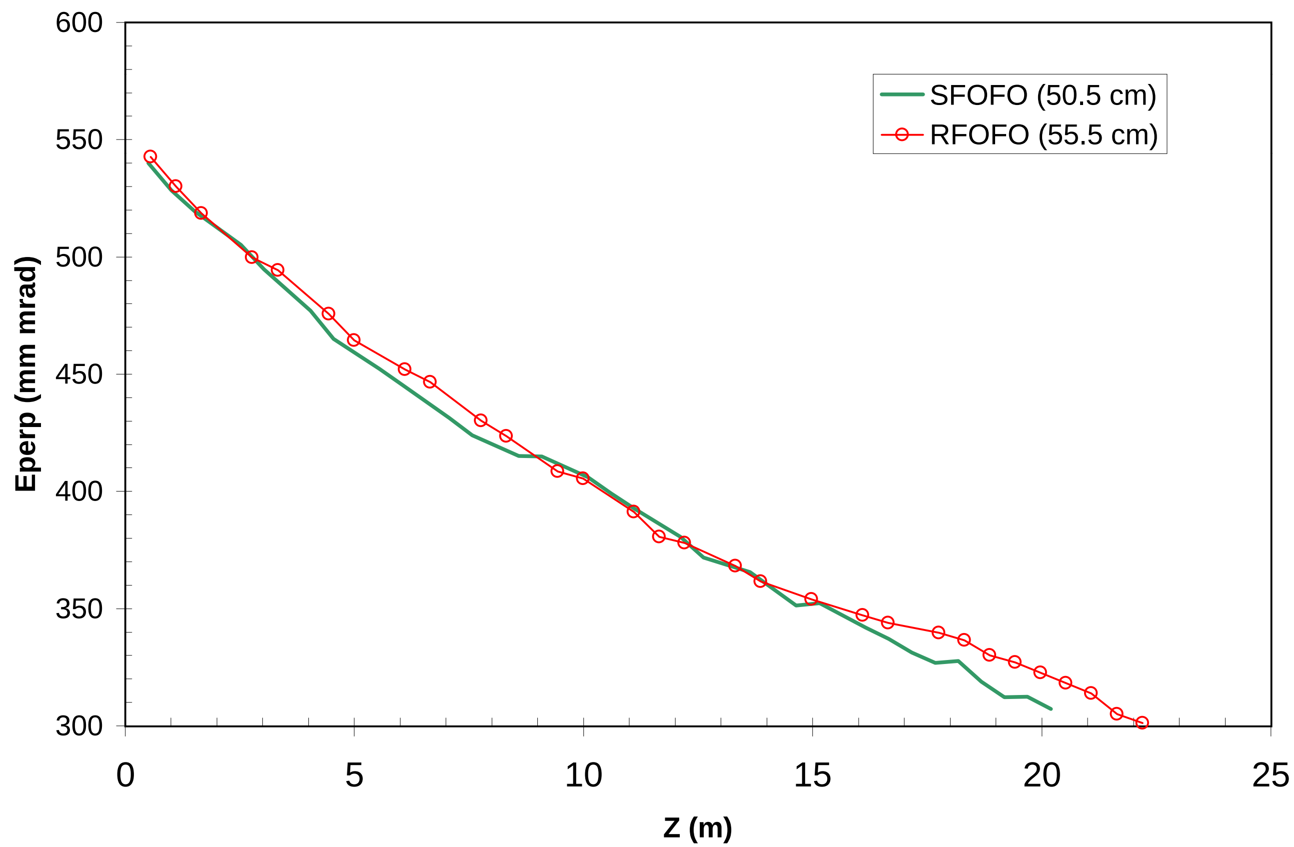


Schematic (not to scale)

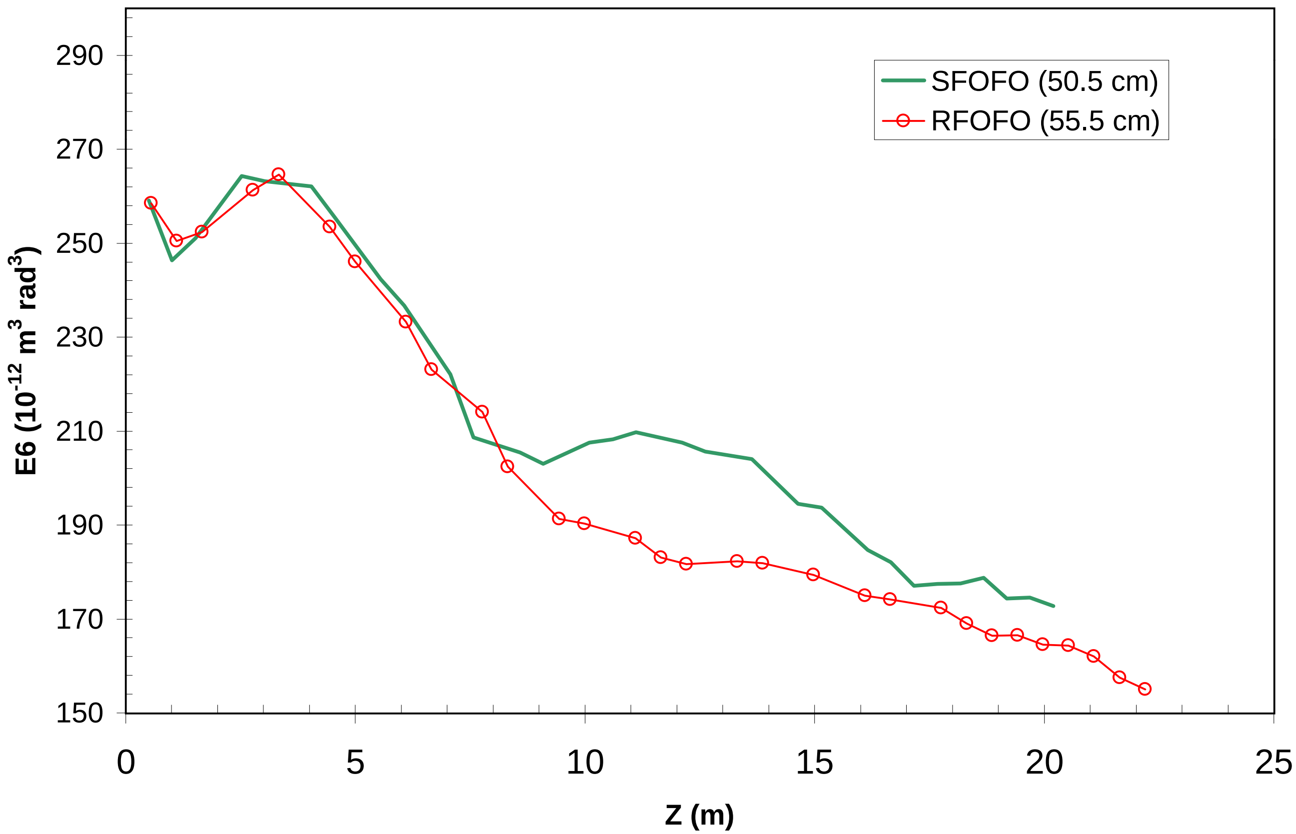
Palmer's sFOFO



- 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.

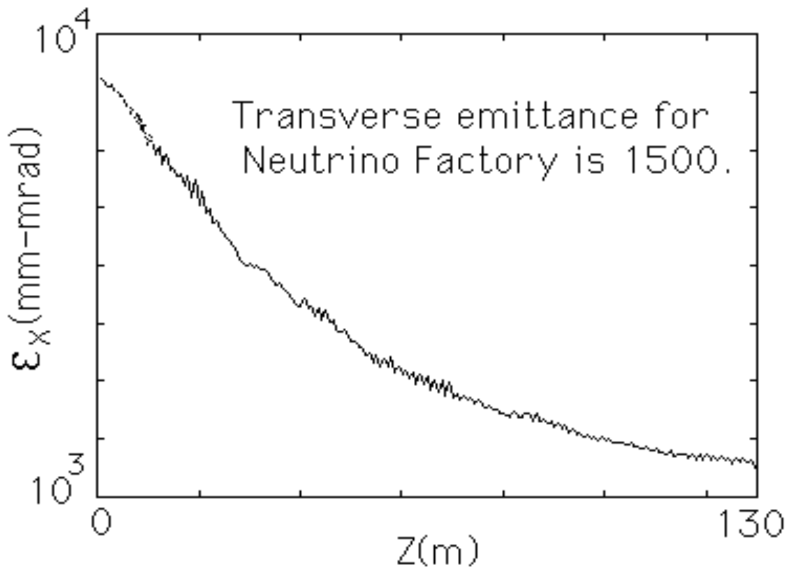


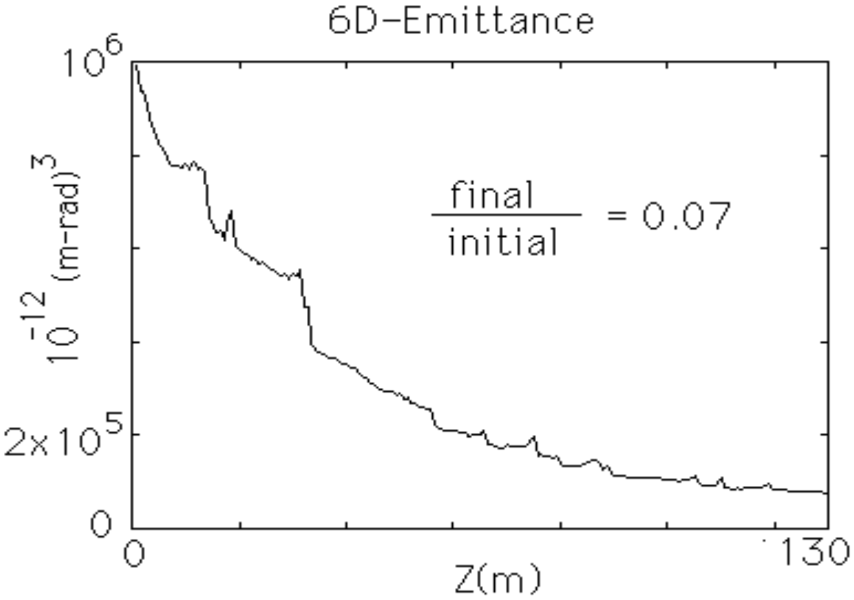
Full 6D emittance as a function of distance for the SFOFO and stretched RFOFO lattices. Peak field is roughly 10 T, and central beam momentum is 125 MeV/c. There are no beam correlations.

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.**

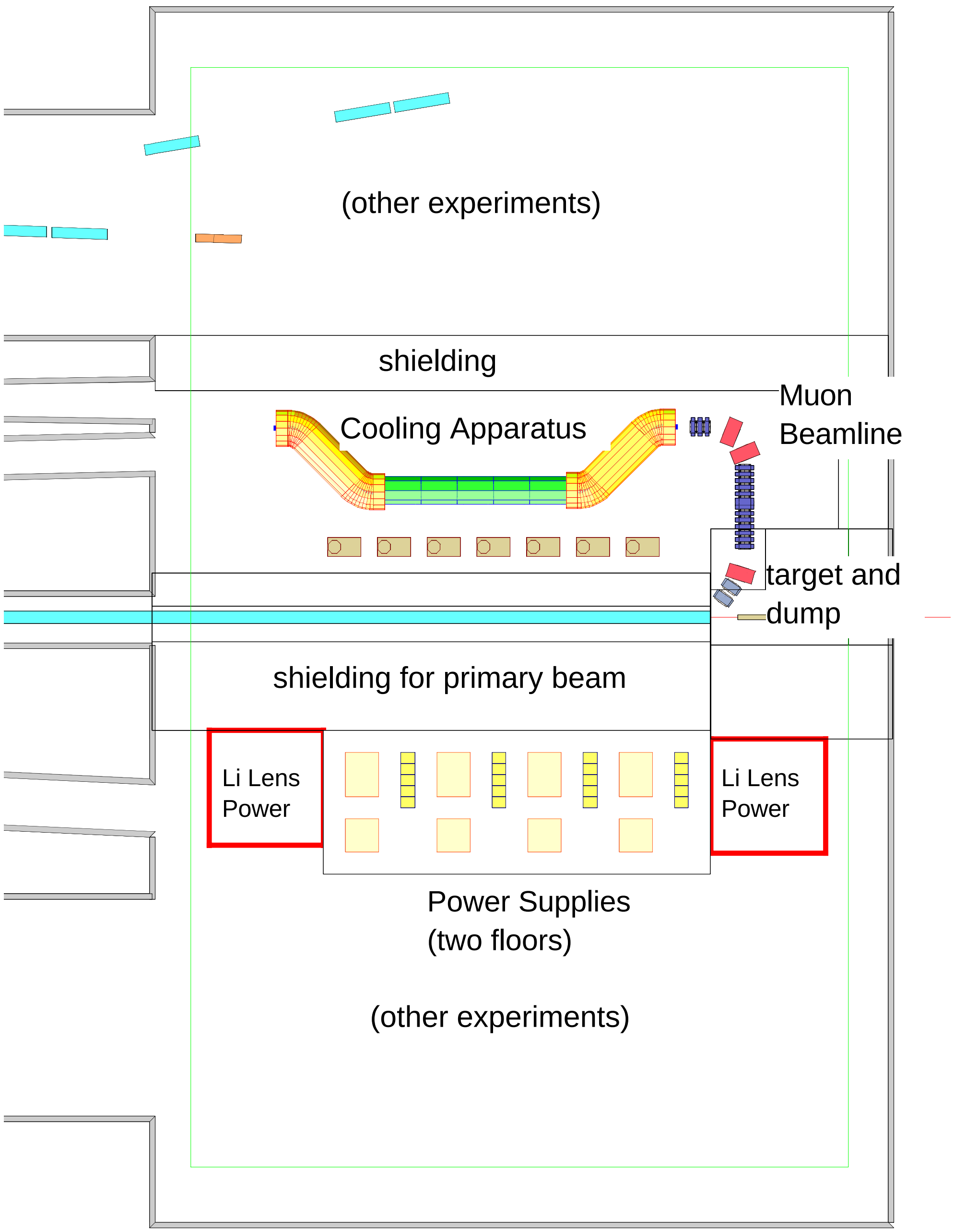
4. **Design a (15 T) alternating solenoid transverse cooling section corresponding to a cooling stage towards the end of the cooling channel. This includes the RF modules, solenoids, and liquid hydrogen absorbers.**

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

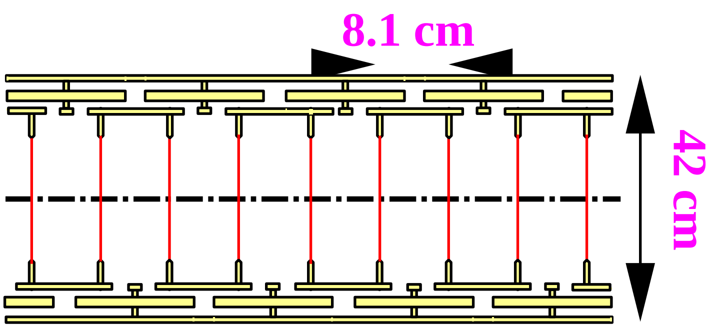


Example: The MCenter Beamline

MUCOOL RF R&D

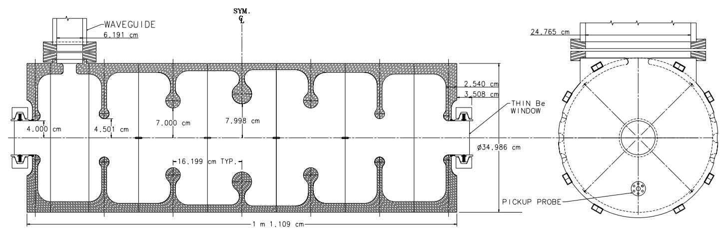
BNL, FNAL, LBNL, Mississippi

Be window cavity design



$\pi/2$ 805 MHz Interleaved Cavity

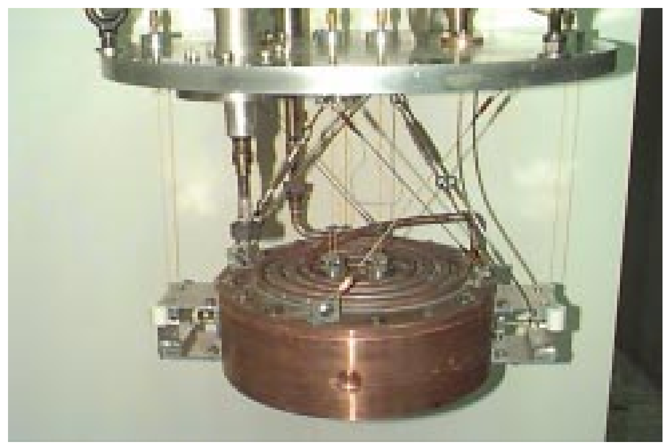
Open cell cavity design



Standing wave linac structure

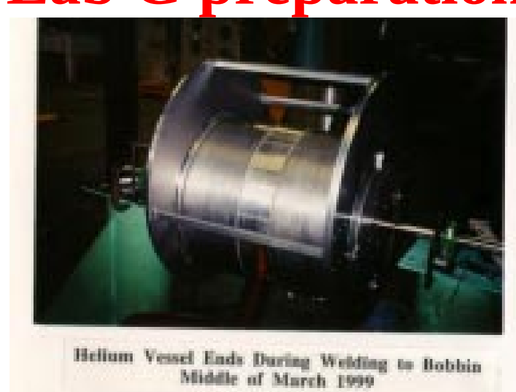
Be window tests

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

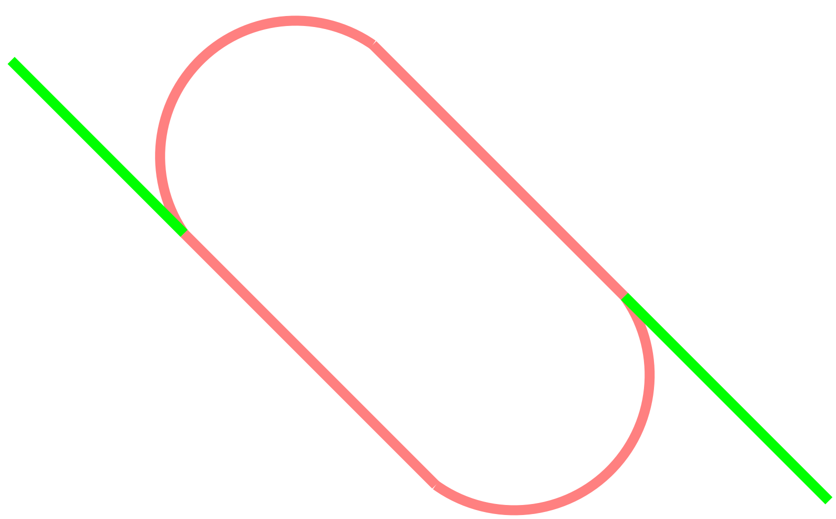
Storage Rings

CERN,FNAL

Racetrack

Supports two detectors

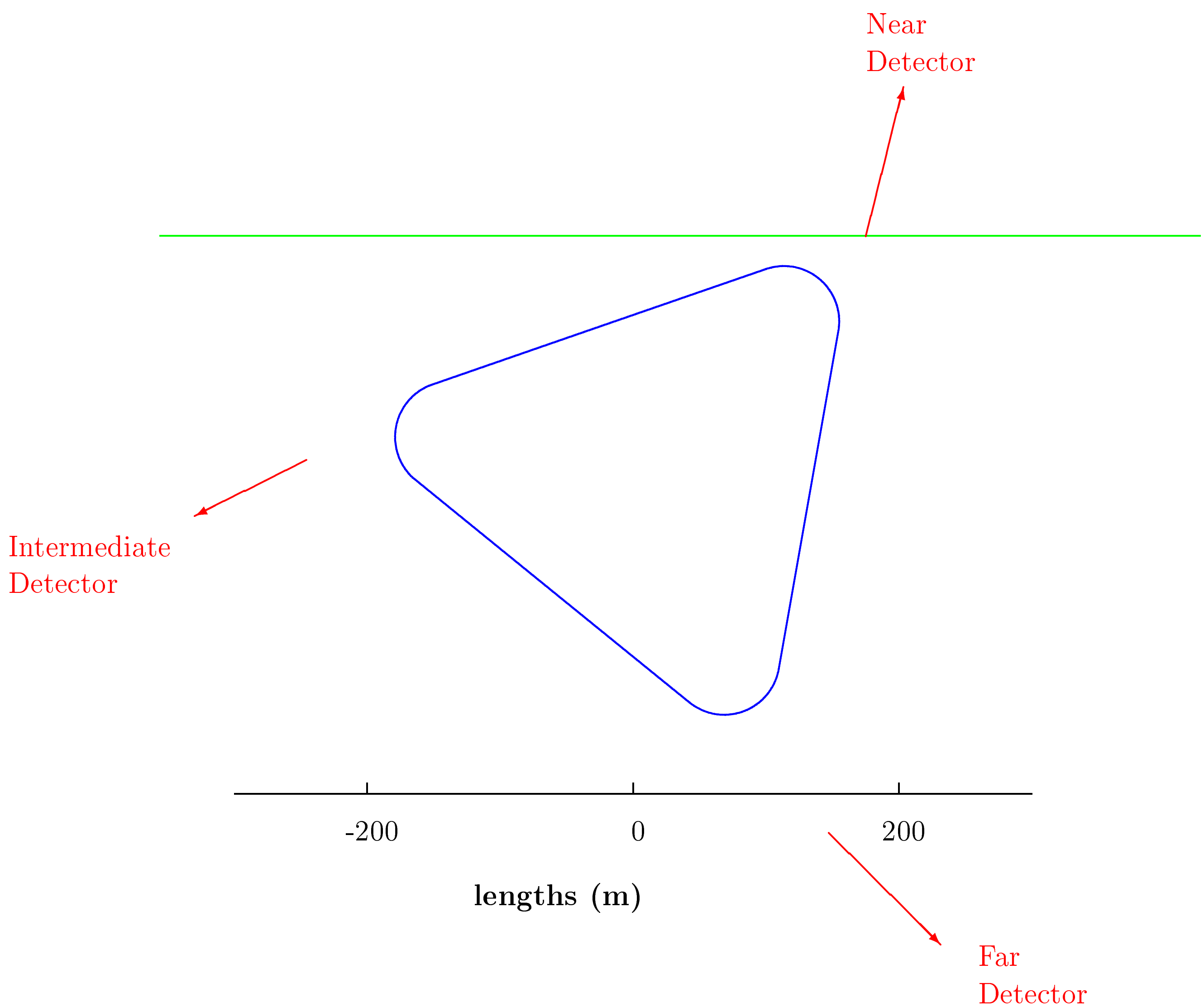
Near



Far

Triangular Ring

Supports three detectors



Modified Figure 8

Supports three detectors