Proton Driver for Super Neutrino Beam

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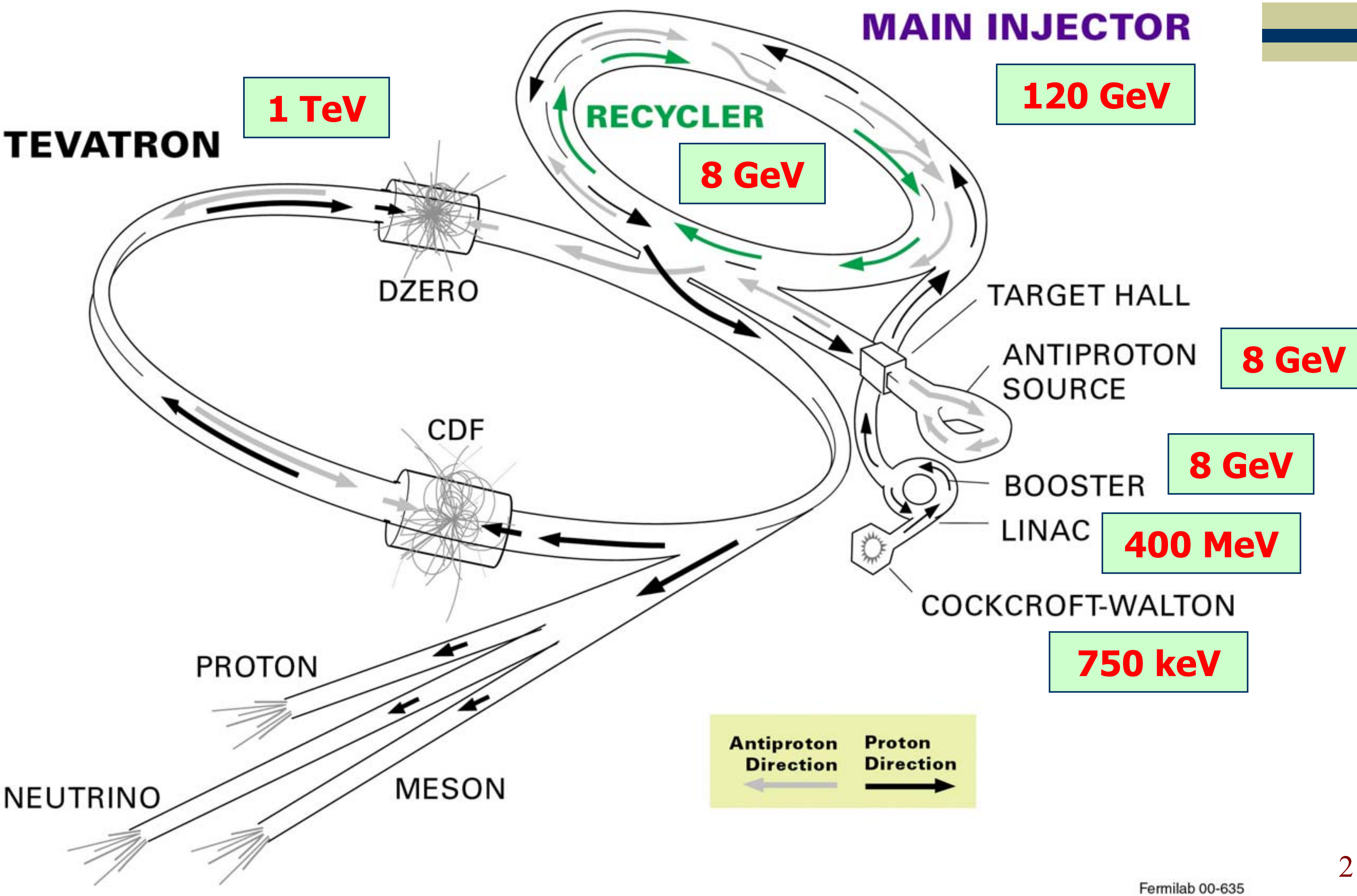
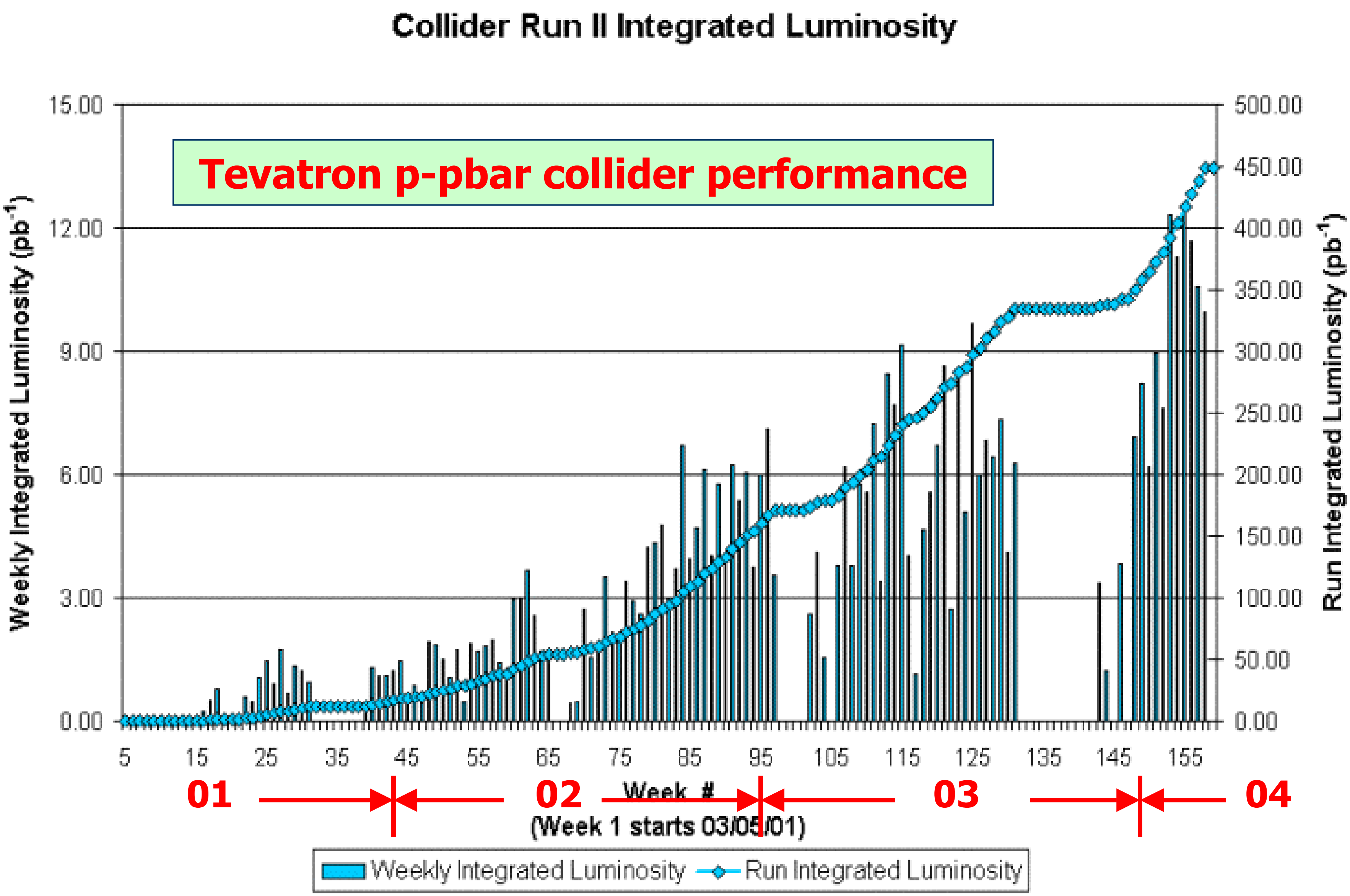
http://www-bd.fnal.gov/pdriver/

Fermilab Accelerator Complex



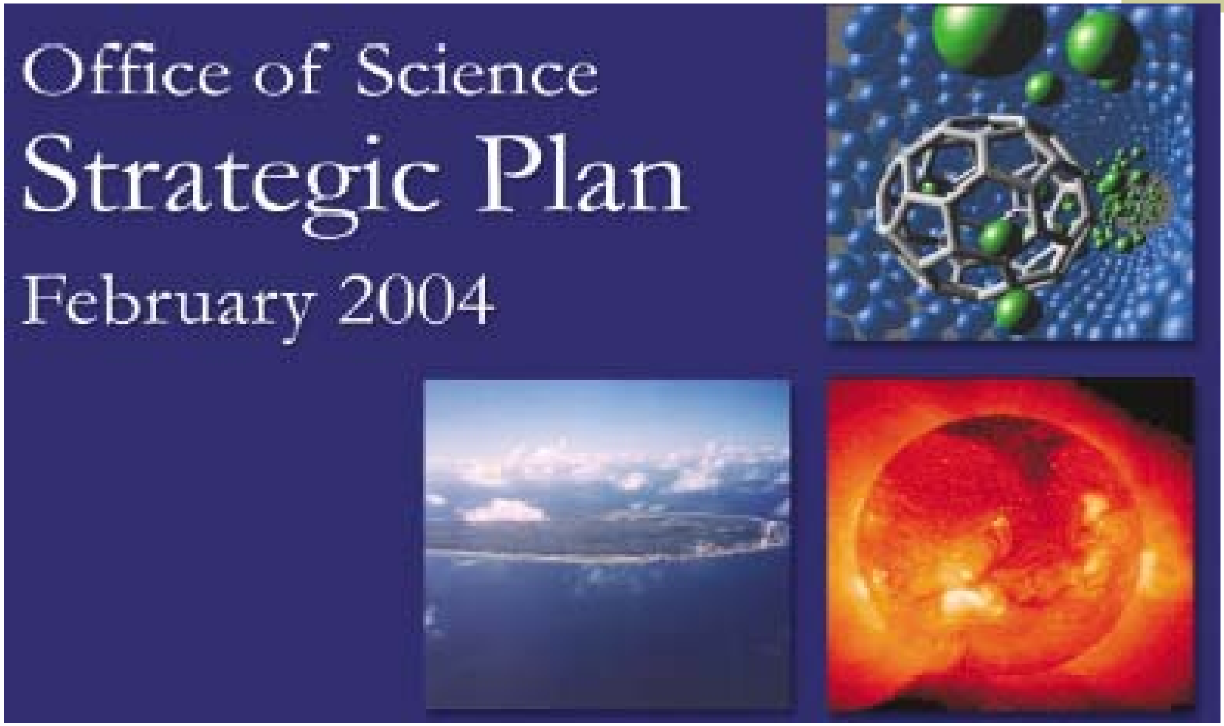


Collider Run II Integrated Luminosity
Tevatron p-pbar collider performance
15.00
12.00
9.00
6.00
3.00
0.00
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Weekly Integrated Luminosity (pb-1)
Run Integrated Luminosity (pb-1)
5
15
25
35
45
55
65
75
85
95
105
115
125
135
145
155
01
02
03
04
Week #
(Week 1 starts 03/05/01)
Weekly Integrated Luminosity
Run Integrated Luminosity

Outline

- Introduction
  - U.S. Department of Energy's (DOE's) 20-year strategic plan
  - What is Super Neutrino Beam
  - What is Proton Driver
  - Proton Drivers around the world
- Fermilab's Proton Driver Plan
  - Long Range Planning Committee recommendation
  - 8 GeV superconducting linac design
  - 8 GeV rapid cycling synchrotron design
  - 2 MW Main Injector Upgrade
- Summary

U.S. Dept of Energy's 20-Year Road Map



- Listed 28 new major facilities across the field (fusion energy, materials, biological and environmental science, high energy & nuclear physics, advanced computation)
- 4 HEP projects: Linear Collider, BTEV, JDEM and *Proton driver*

Super Neutrino Beam & Proton Driver

Priority: Tie for 21
Super Neutrino Beam

The Facility: The Super Neutrino Beam will allow more comprehensive studies of neutrino properties by producing a neutrino beam 10 times more intense than those available with current accelerators.

Background: Neutrinos are the most poorly understood of the elementary particles but may be the most important for answering fundamental questions ranging from why there is any matter in the universe at all, to how all particles and forces in the universe "unify" into a simple picture. Because neutrinos rarely interact with matter (many billions pass through each of us every second), the ability to generate controlled beams containing large numbers of neutrinos greatly increases the ability to study them.

What's New: **The Super Neutrino Beam will be powered by a new, megawatt class "proton driver"** which will be able to provide an intense, well-controlled neutrino beam - with 10 times more neutrinos per second than are available from any existing facility - to detectors hundreds or thousands of miles distant.

Applications: The 2002 Nobel Prize in physics was shared by two scientists—one American and one Japanese—for their path-breaking measurements of solar and atmospheric neutrinos. Their research strongly suggested that neutrinos have mass and oscillate among three types as they travel through space. These oscillations have recently been confirmed, and the properties and behavior of neutrinos are now ripe for measurement. The results will have profound implications for our understanding of the fundamental properties of matter and the evolution of the early universe.

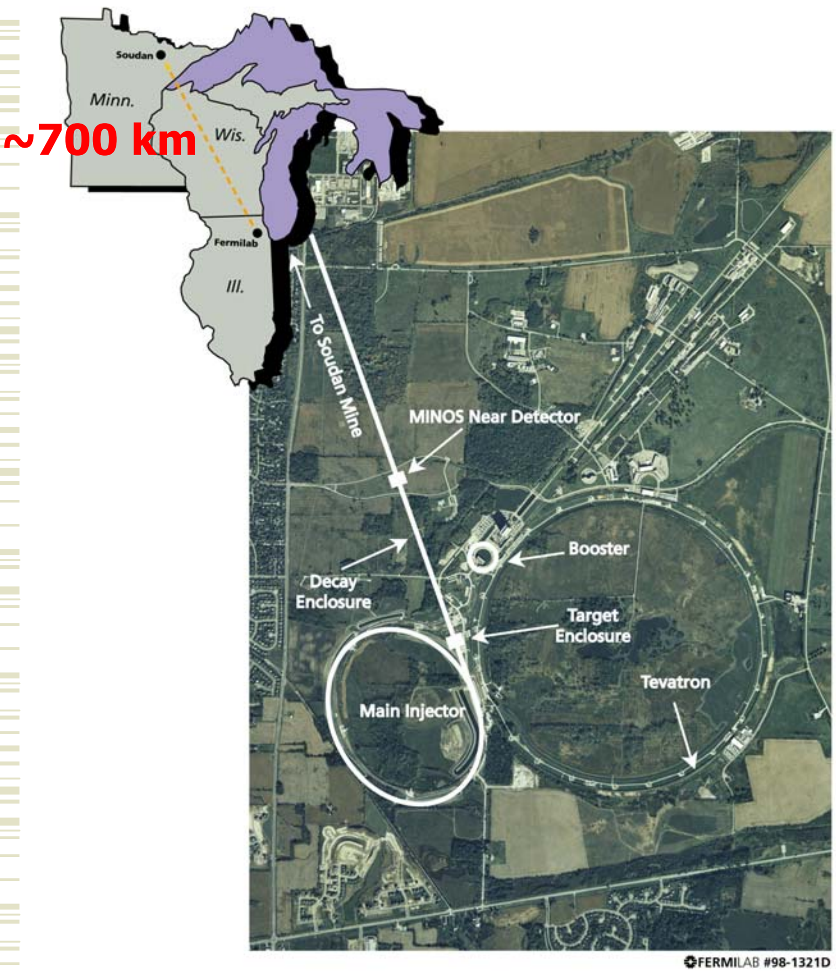
What is Super Neutrino Beam?

- "Super" means high flux
- "Super" also means long baseline
- But it is NOT neutrino factory beam
- It is *conventional* neutrino beam, i.e., neutrinos from pion decay (not from muon decay)

What is Proton Driver?

- Strictly speaking, a Proton Driver is not just a MW-class proton source.
- It should exhibit two basic features:
  - Relatively high energy (> 4 GeV) so that it can produce both π^+ and π^- particles and high energy neutrinos
  - Short bunch length (a few ns) so that higher yield in polarized pions can be achieved
- Such a proton driver not only can be used for super neutrino beam, but also can serve as the first stage of a neutrino factory and a muon collider.
- At this moment, however, most interest is focused on MW-class only.

neutrinos@fermilab: MiniBooNE and NuMI

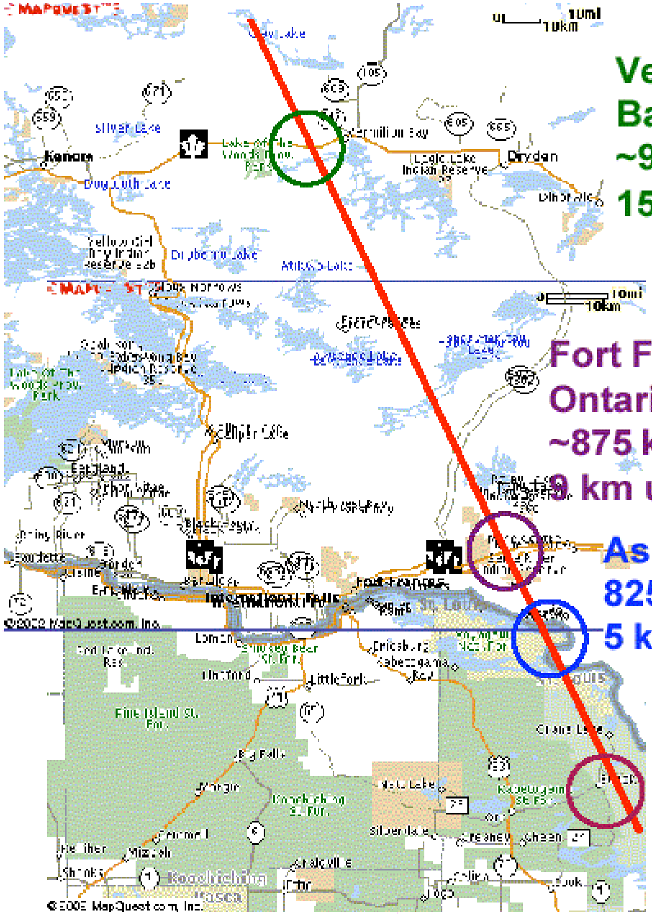


- **MiniBooNE: 8 GeV Booster protons, ν short baseline**
- **NuMI: 120 GeV Main Injector protons (0.3 MW), ν to Soudan**

New Proposal: Off-Axis Experiment

FLRP

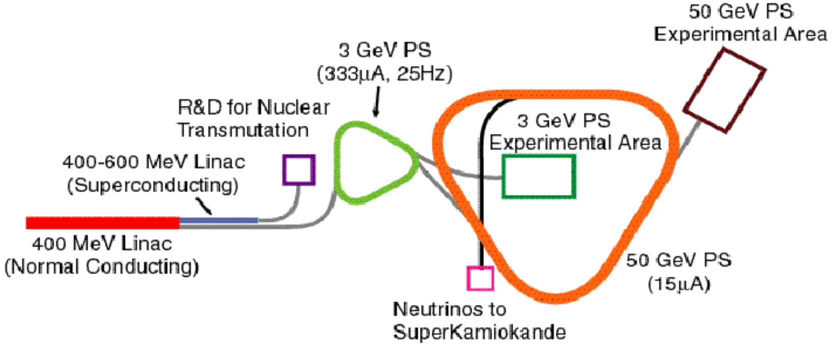
We are now focusing on the Ash River site.



NuMI extension: Off-axis neutrino experiment with a new detector at a new location

Japan: K2K and JPARC-K

(H. Yokomizo's talk)

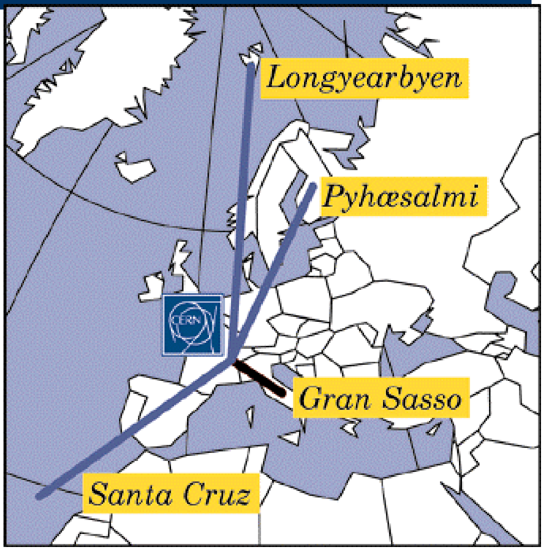


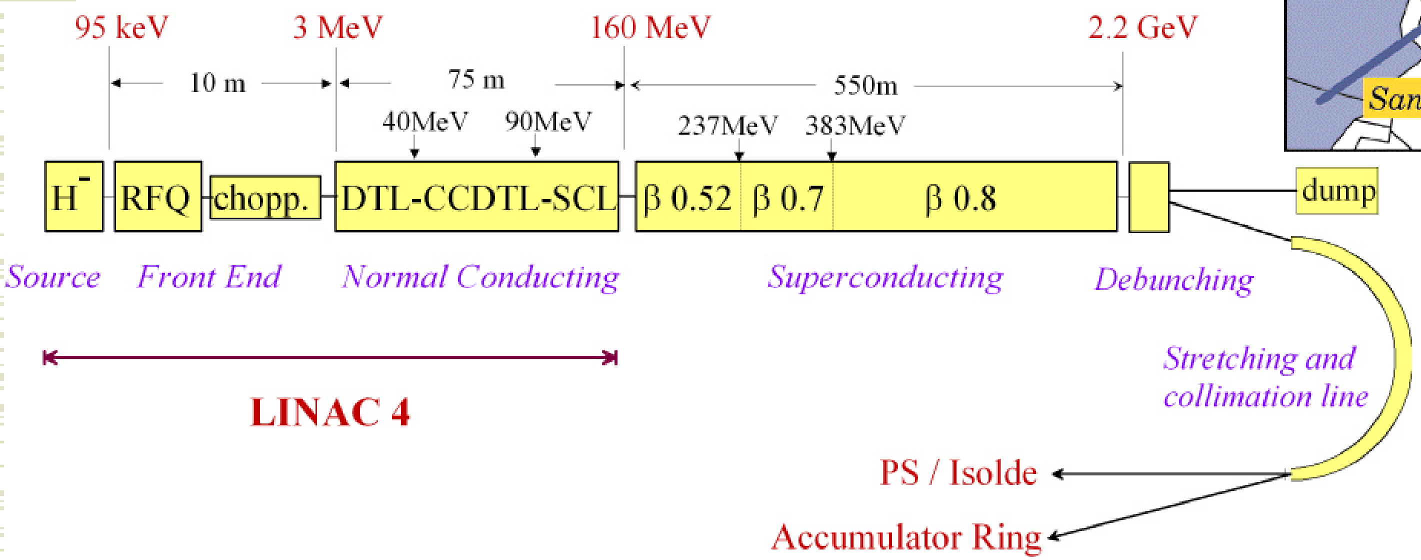
- **KEK: 12 GeV PS protons, ν to Kamiokande**
- **JPARC: 50 GeV protons (0.75 MW), ν to Kamiomande**

CERN: CNGS and SPL

(E. Metral's talk)

- **CNGS: 450 GeV SPS protons, ν to Gran Sasso**
- **SPL: new 2.2 GeV sc proton linac**

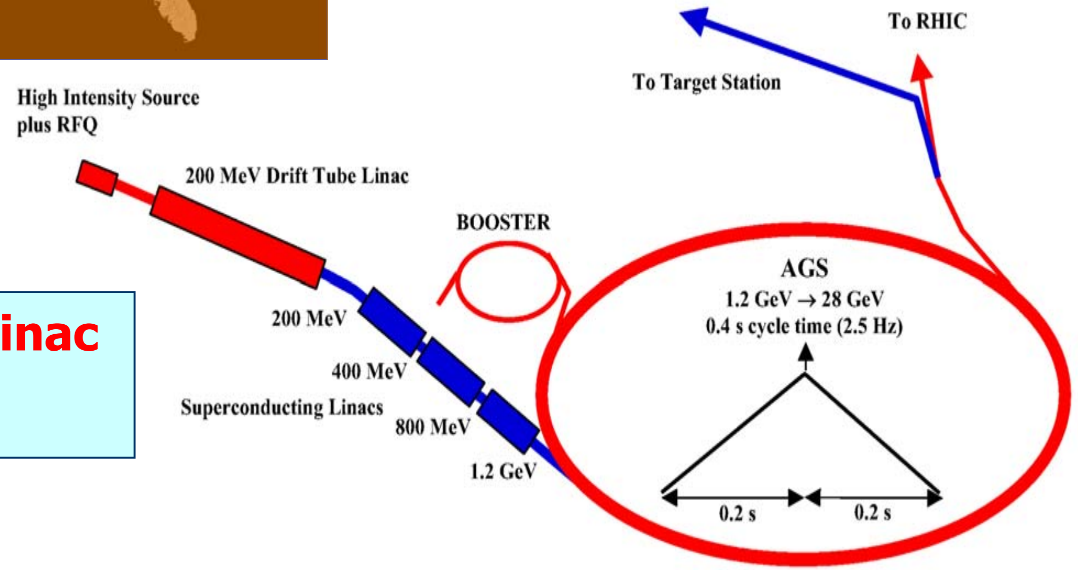




BNL: AGS Upgrade

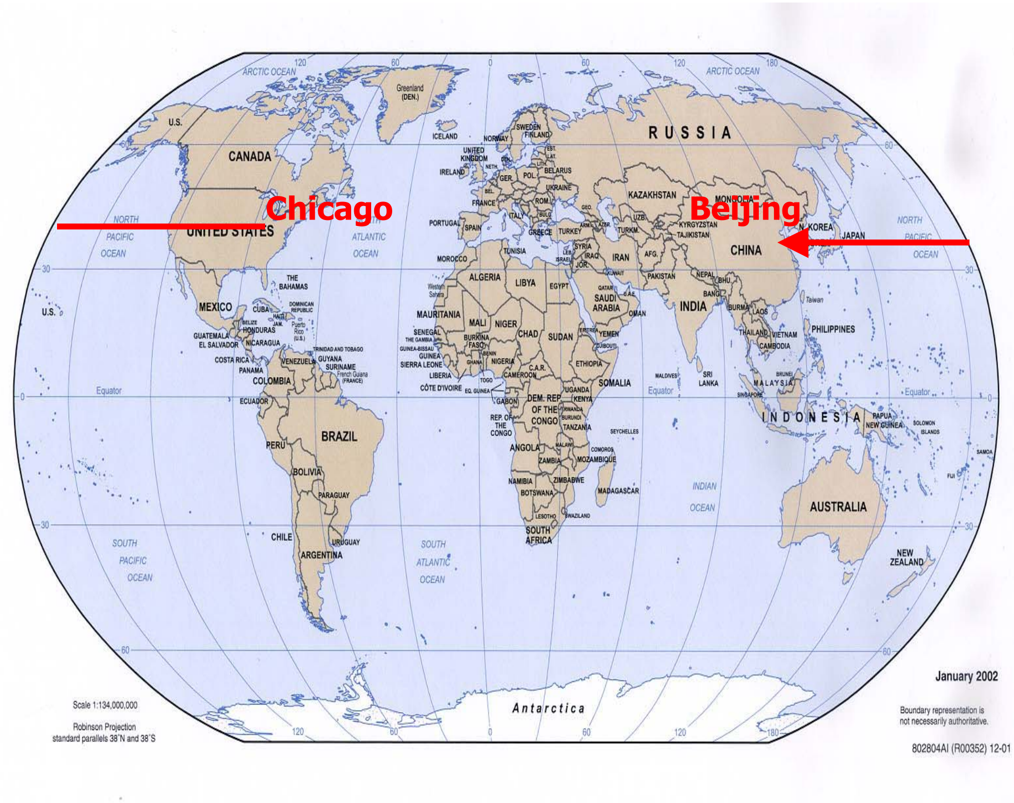
(B. Weng's paper)

BNL- Homestake long baseline

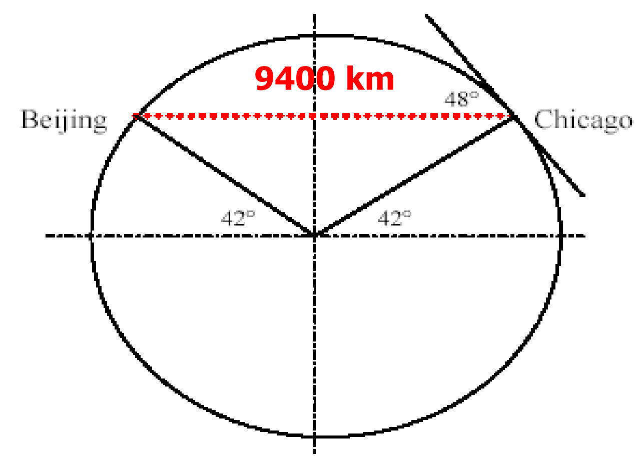


- **New 1.2 GeV sc proton linac**
- **1 MW AGS upgrade**

New Study: Fermilab – Beijing Long Baseline

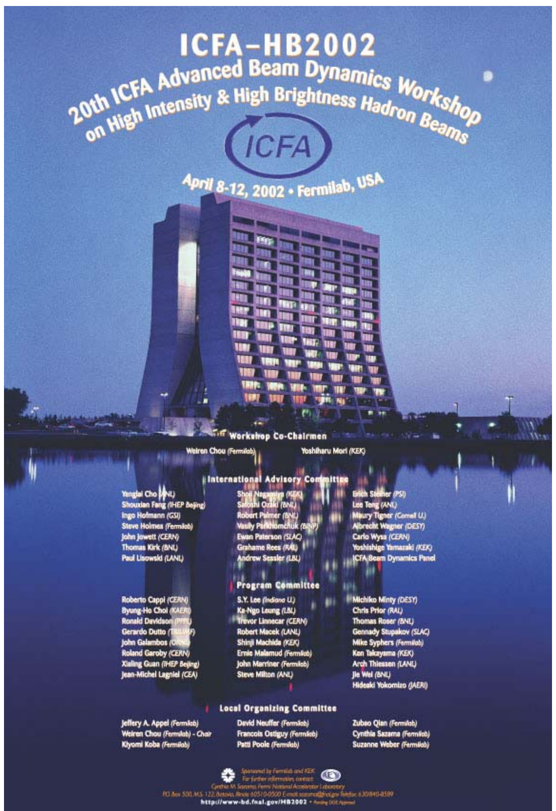


	Latitude	Longitude
Chicago	41:50:13 N	87:41:06 W
Beijing	39:55:00 N	116:23:00 E
Tokyo	35:41:00 N	139:44:00 E



ICFA Workshops

HB2002 Workshop



HB2004 Workshop

Preliminary announcement

(page to be updated soon)

ICFA – HB2004

33rd ICFA Advanced Beam Dynamics Workshop

High Intensity High Brightness Hadron Beams

Bensheim / Darmstadt, Germany
October 18 – 22, 2004

The 33rd ICFA Advanced Beam Dynamics Workshop will take place from October 18 to 22, 2004 in Bensheim (near Darmstadt), Germany. With the theme "High Intensity and High Brightness Hadron Beams" this workshop is a follow-up of the very successful **20th ICFA Advanced Beam Dynamics Workshop** held at Fermilab April 8-12, 2002. Topics include accelerator and beam physics issues associated with high intensity and/or brightness, technical system designs, reviews of existing machines and overviews of planned projects for protons and ions.

Fermilab’s Proton Driver Plan

- Fermilab Director formed a Long Range Planning Committee about a year ago for advice to plan for the lab’s future.
- The committee has completed its task and is finalizing a report.
- The report will recommend the Proton Driver as a future construction project at Fermilab.
- Fermilab Director has started a new Proton Driver study. The goal is to complete the documentation required by DOE’s CD-0 (Critical Decision Zero) process by the end of 2004.
- The Proton Driver project is defined as:

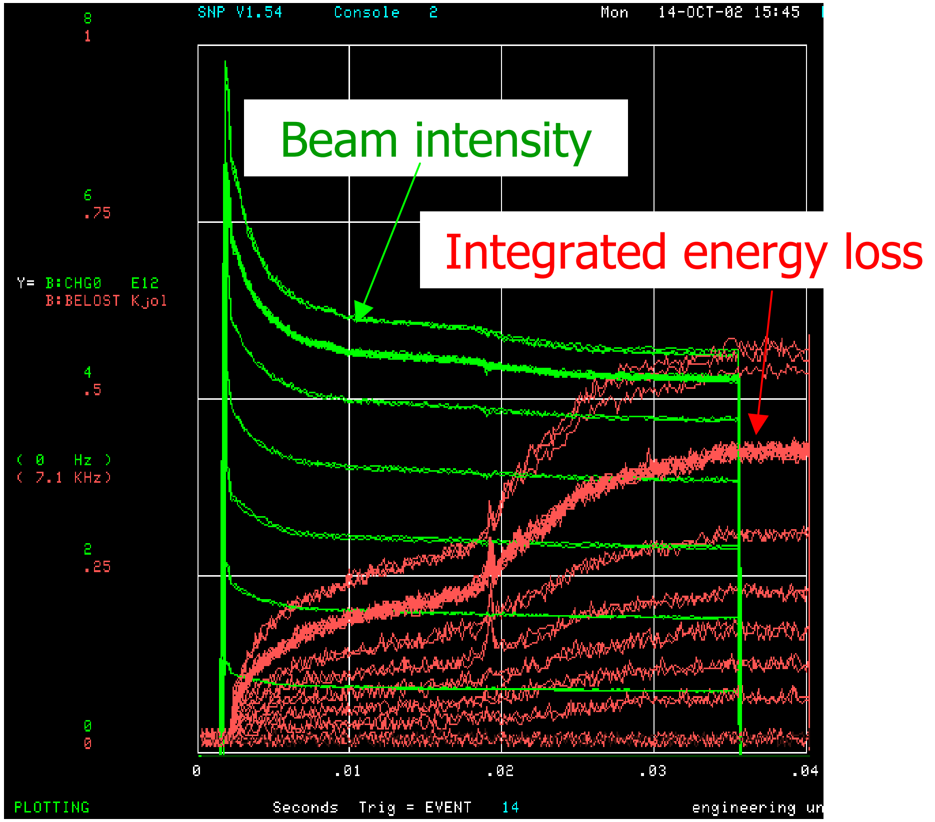
    "a complete replacement of our current 400 MeV linac and 8 GeV Booster, accompanied by Main Injector upgrades."

Fermilab's Proton Driver Plan (cont…)

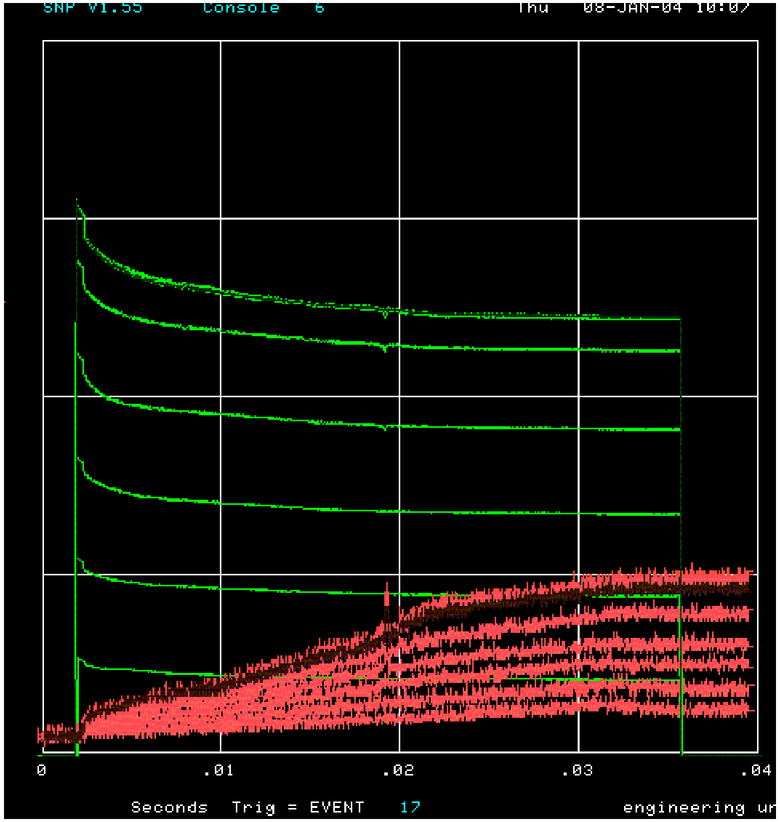
- Beam power specification:
  - 8 GeV Proton Driver: $\geq$ 0.5 MW
  - Upgraded Main Injector: 2 MW
  - Total beam power: $\geq$ 2.5 MW
- Two options:
  - 8 GeV sc linac
  - 8 GeV synchrotron
- The linac is the preferred one.
- But technology decision won't be made until 2005.
- A crucial part of this study is to have a better understanding of the cost differential between the two options.

Booster - the Bottleneck

2 years ago

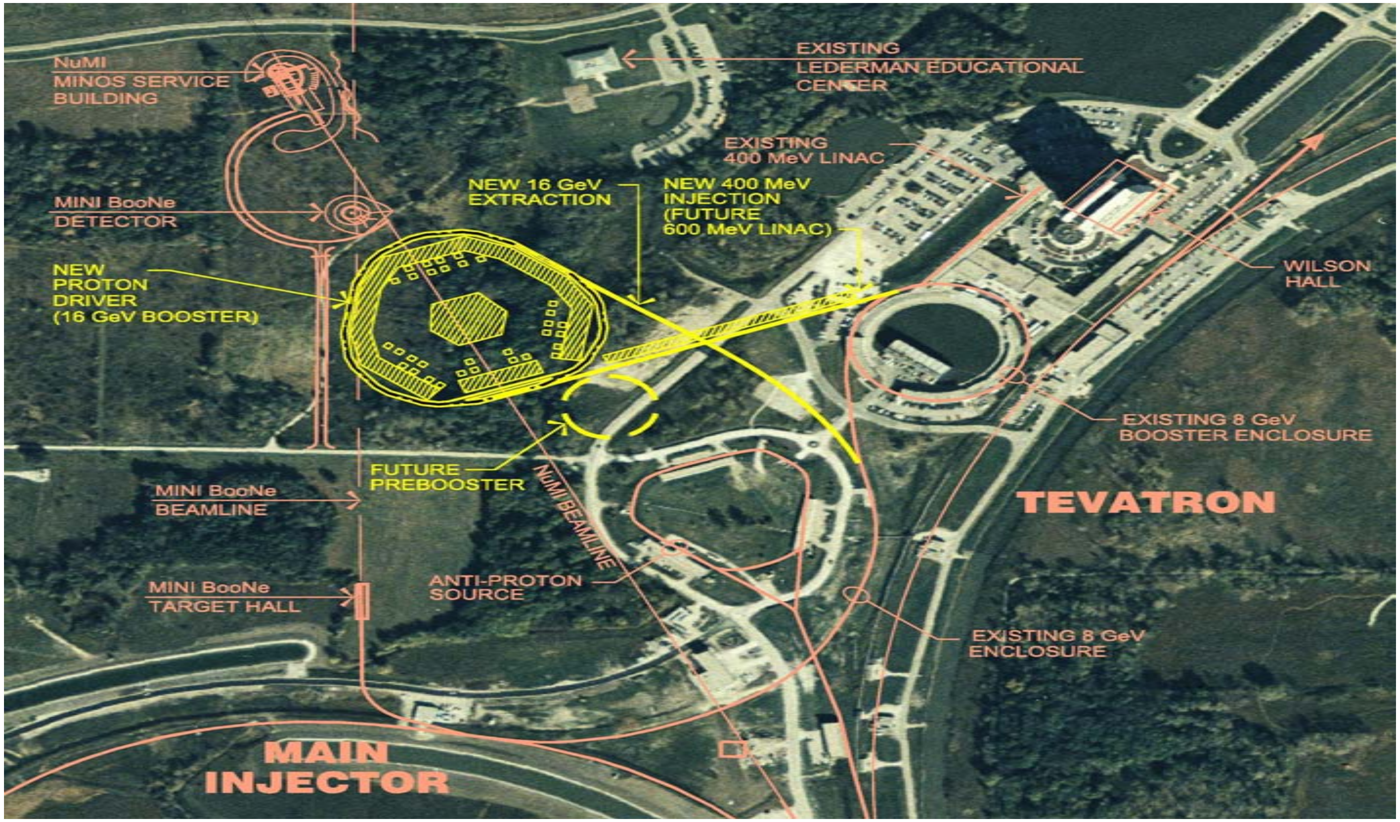


Now

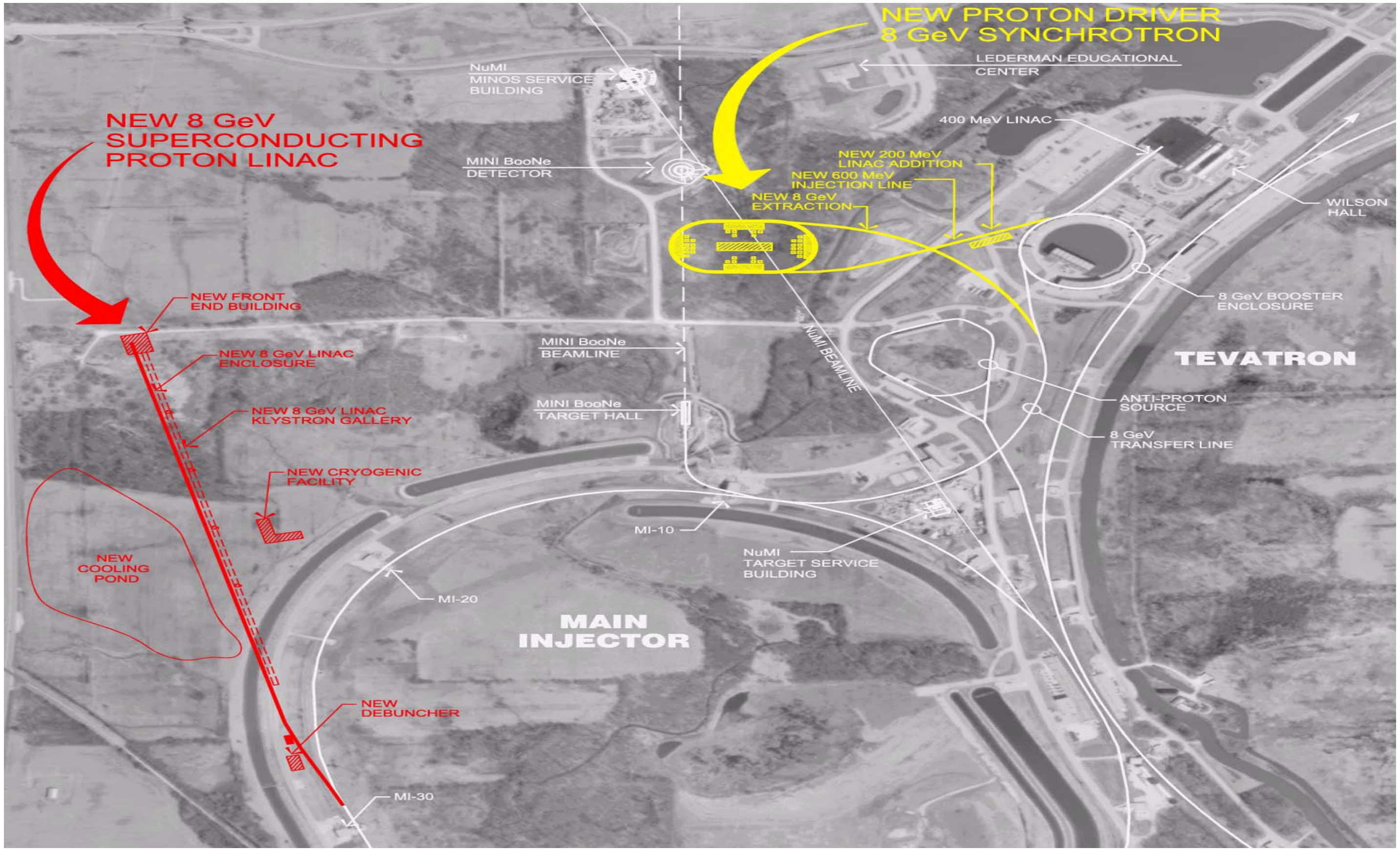


Proton Driver Study I: 16 GeV

(Fermilab-TM-2136, Dec 2000)



Proton Driver Study II: 8 GeV
(Fermilab-TM-2169, May 2002)



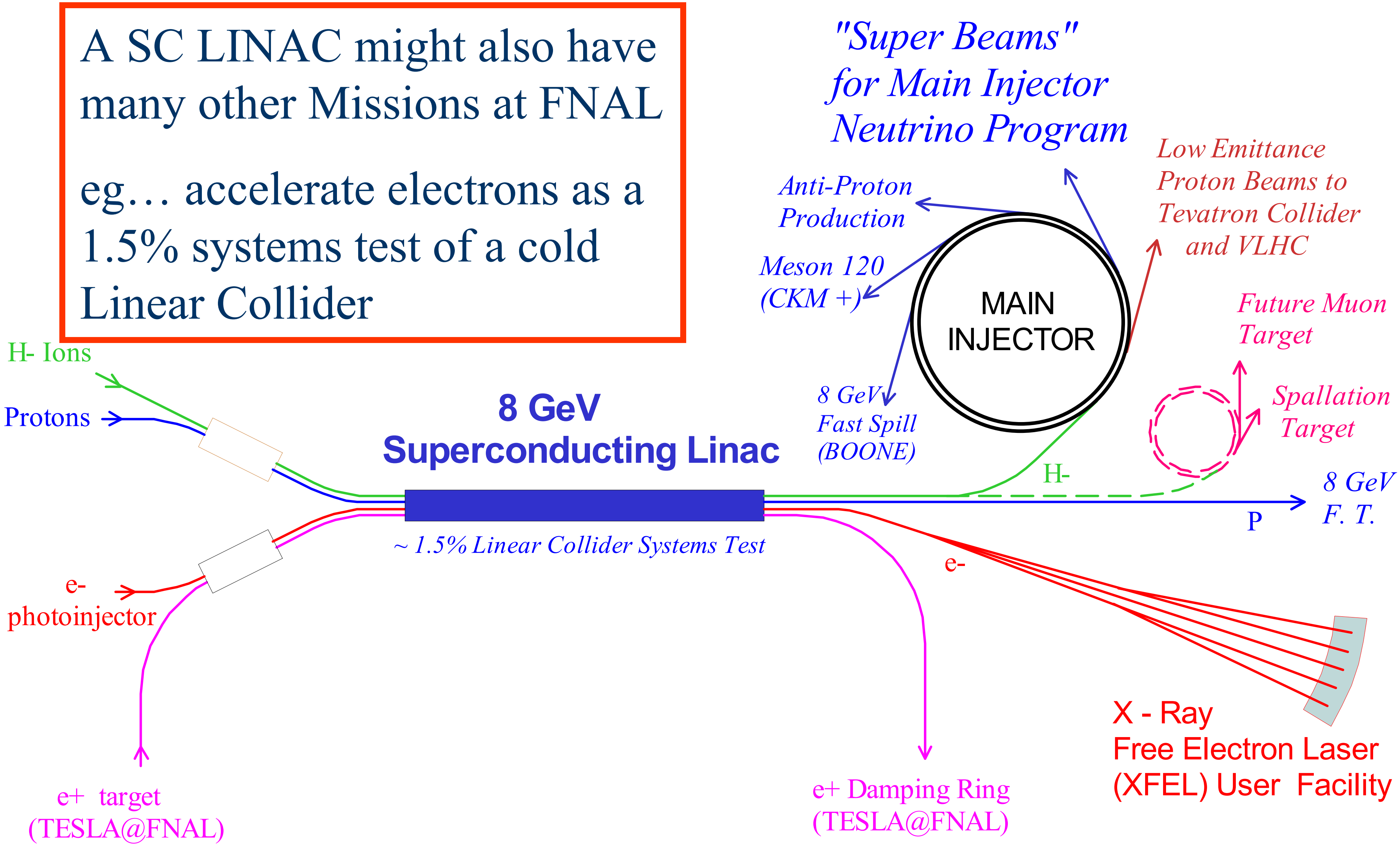
(1) 8 GeV SC Linac Parameters

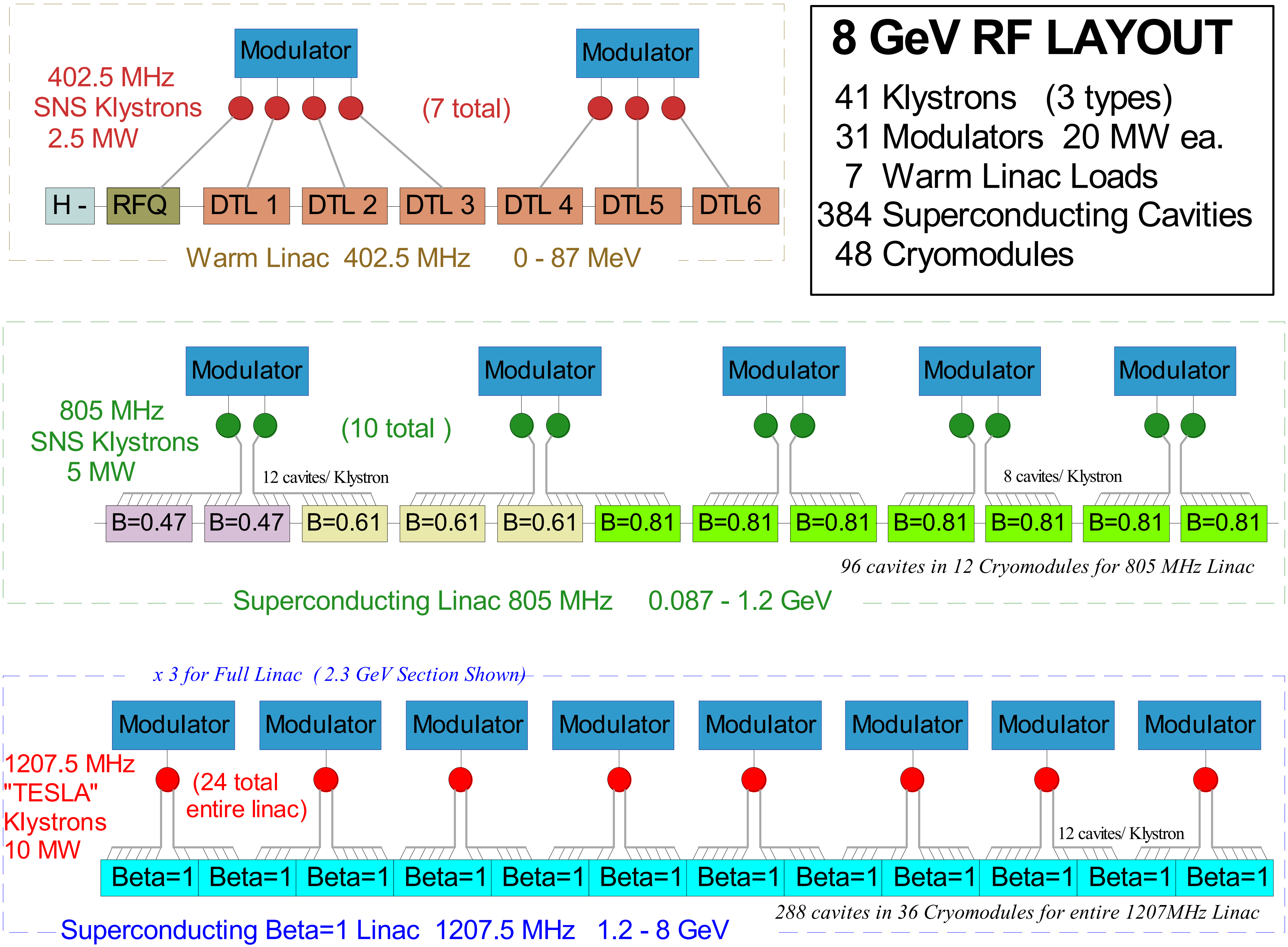
Energy	GeV	8
Particle type	H^-, electrons	
Rep rate	Hz	10
Active length	m	671
Beam current	mA	25
Pulse length	ms	1
Beam intensity	p/pulse p/hour	1.5×10^{14} 5.4×10^{18}
Beam power	MW avg. MW peak	2 (0.5) 200

Multi-Mission 8 GeV Injector Linac

A SC LINAC might also have many other Missions at FNAL

eg… accelerate electrons as a 1.5% systems test of a cold Linear Collider





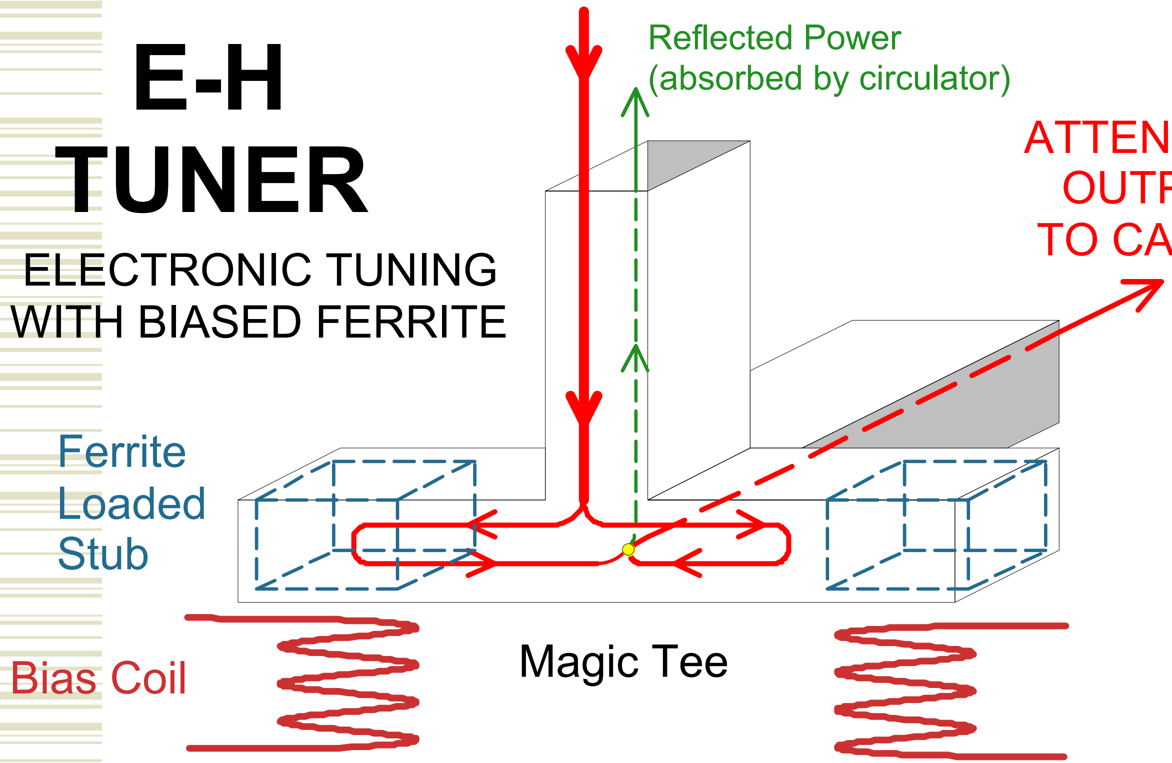
8 GeV RF LAYOUT
41 Klystrons (3 types)
31 Modulators 20 MW ea.
7 Warm Linac Loads
384 Superconducting Cavities
48 Cryomodules
Modulator
Modulator
402.5 MHz
SNS Klystrons
2.5 MW
(7 total)
H -
RFQ
DTL 1
DTL 2
DTL 3
DTL 4
DTL5
DTL6
Warm Linac 402.5 MHz 0 - 87 MeV
Modulator
Modulator
Modulator
Modulator
Modulator
805 MHz
SNS Klystrons
5 MW
(10 total)
12 cavites/ Klystron
8 cavites/ Klystron
B=0.47
B=0.47
B=0.61
B=0.61
B=0.61
B=0.81
B=0.81
B=0.81
B=0.81
B=0.81
B=0.81
B=0.81
96 cavites in 12 Cryomodules for 805 MHz Linac
Superconducting Linac 805 MHz 0.087 - 1.2 GeV
x 3 for Full Linac (2.3 GeV Section Shown)
Modulator
Modulator
Modulator
Modulator
Modulator
Modulator
Modulator
Modulator
1207.5 MHz
"TESLA"
Klystrons
10 MW
(24 total
entire linac)
12 cavites/ Klystron
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
288 cavites in 36 Cryomodules for entire 1207MHz Linac
Superconducting Beta=1 Linac 1207.5 MHz 1.2 - 8 GeV

Electronically Adjustable E-H Tuner

MICROWAVE INPUT POWER
from Klystron and Circulator

E-H
TUNER

ELECTRONIC TUNING
WITH BIASED FERRITE



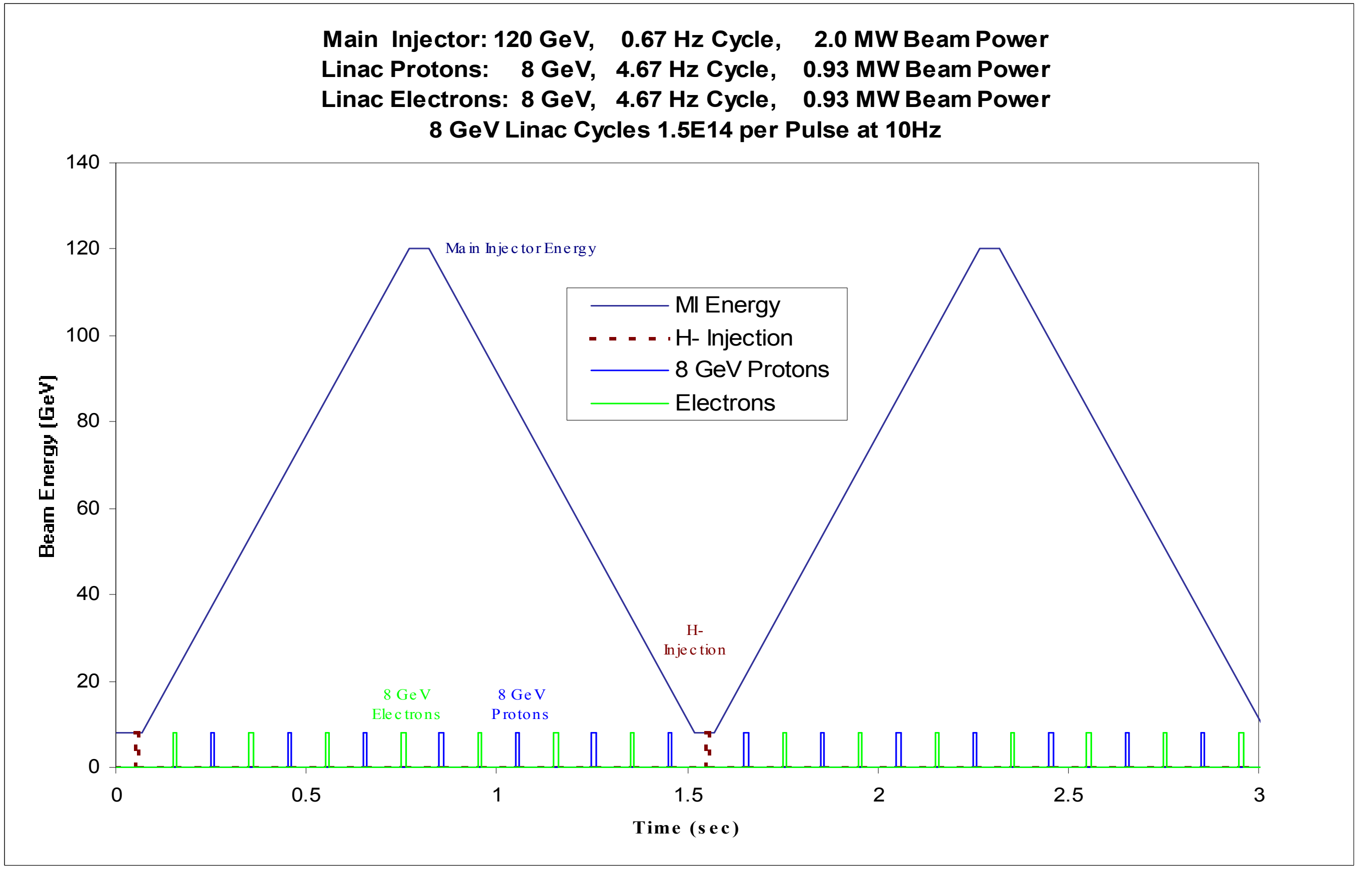
Attractive Price Quote from AFT

(<< Klystron)

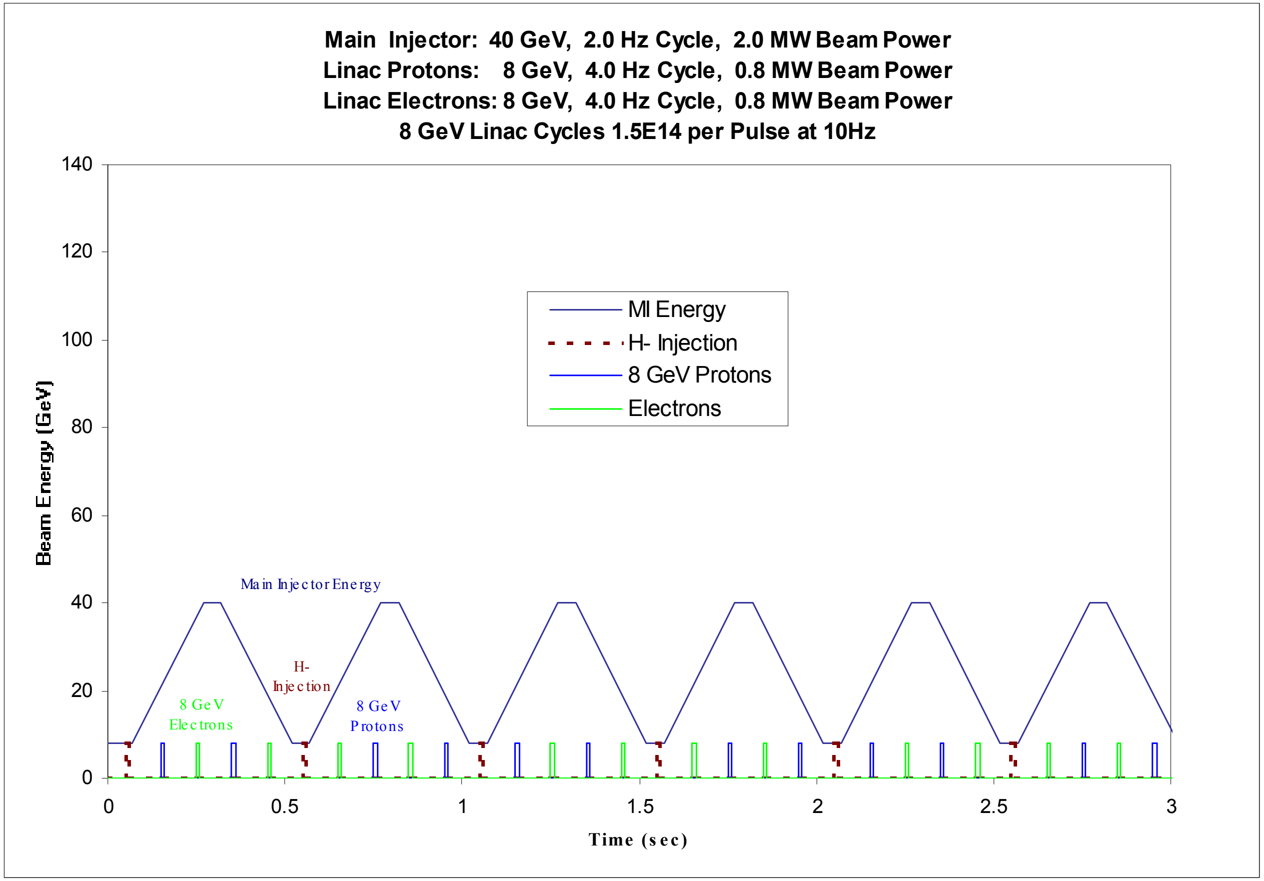
FERRITE LOADED SHORTED STUBS CHANGE ELECTRICAL LENGTH DEPENDING ON DC MAGNETIC BIAS.

TWO COILS PROVIDE INDEPENDENT ***PHASE AND AMPLITUDE*** CONTROL OF CAVITIES

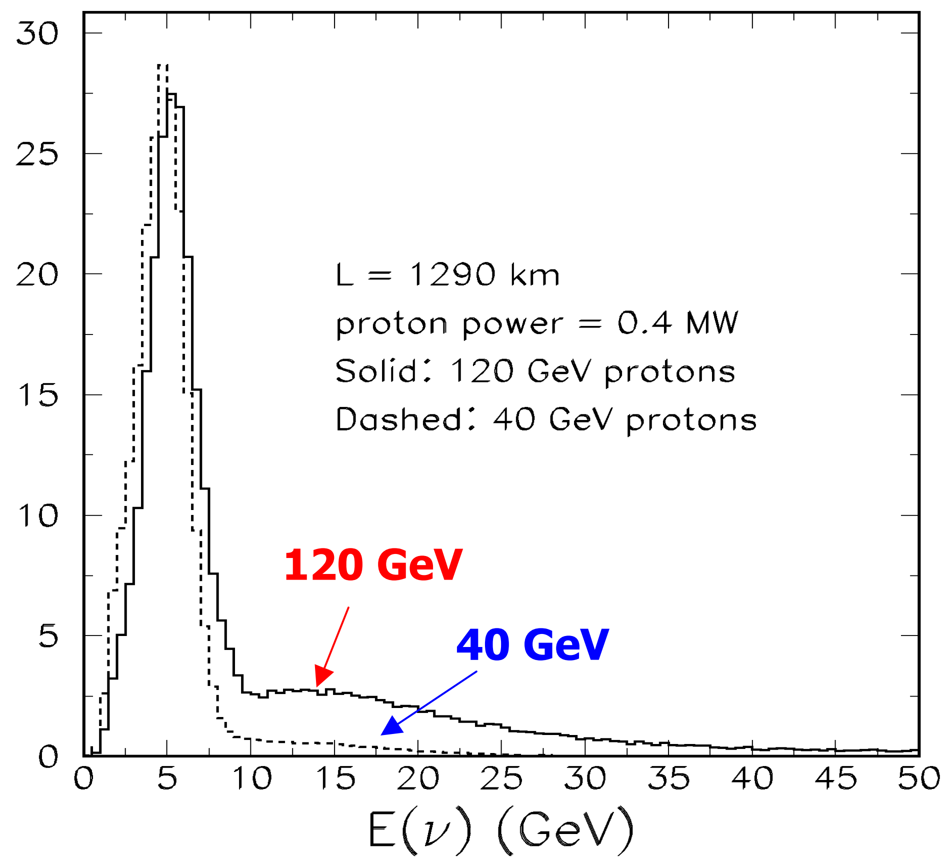
120 GeV Main Injector Cycle (2 MW)



40 GeV Main Injector Cycle (2 MW)



Neutrino Spectrum at Different Proton Energies

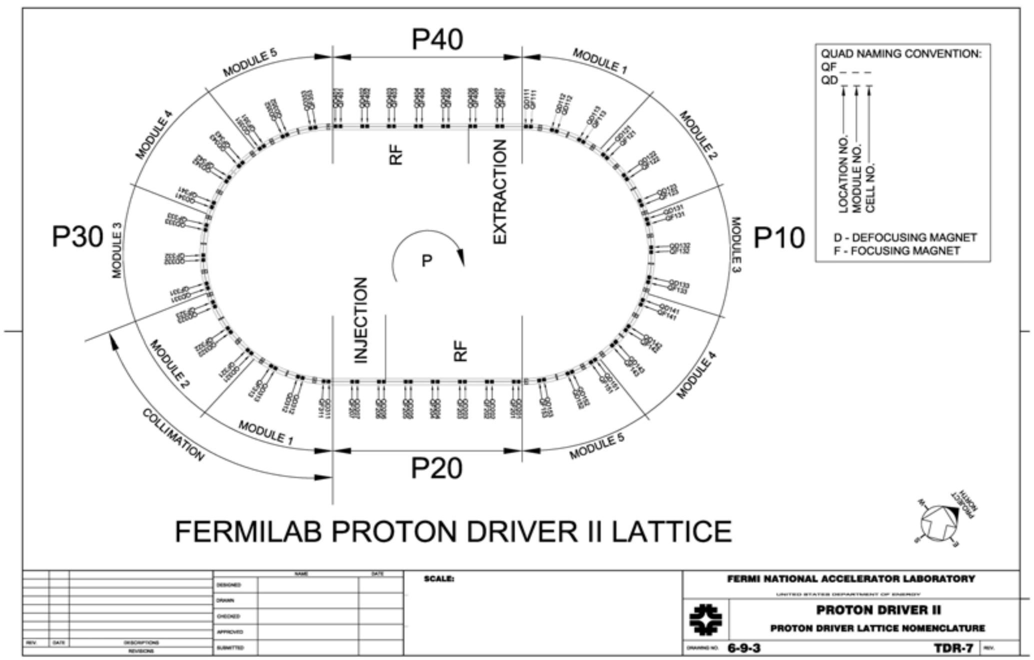


Running at 40 GeV reduces tail at higher neutrino energies

(2) 8 GeV Synchrotron Parameters

Parameters	Present Proton Source	Proton Driver (PD2)
Linac (operating at 15 Hz)		
Kinetic energy (MeV)	400	600
Peak current (mA)	40	50
Pulse length (μs)	25	90
H^- per pulse	6.3×10^{12}	2.8×10^{13}
Average beam current (μA)	15	67
Beam power (kW)	6	40
Booster (operating at 15 Hz)		
Extraction kinetic energy (GeV)	8	8
Protons per bunch	6×10^{10}	3×10^{11}
Number of bunches	84	84
Protons per cycle	5×10^{12}	2.5×10^{13}
Protons per hour	9×10^{16} (@ 5 Hz)	1.35×10^{18}
Normalized transverse emittance (mm-mrad)	15π	40π
Longitudinal emittance (eV-s)	0.1	0.2
RF frequency (MHz)	53	53
Average beam current (μA)	12	60
Beam power (MW)	0.033 (@ 5 Hz)	0.5

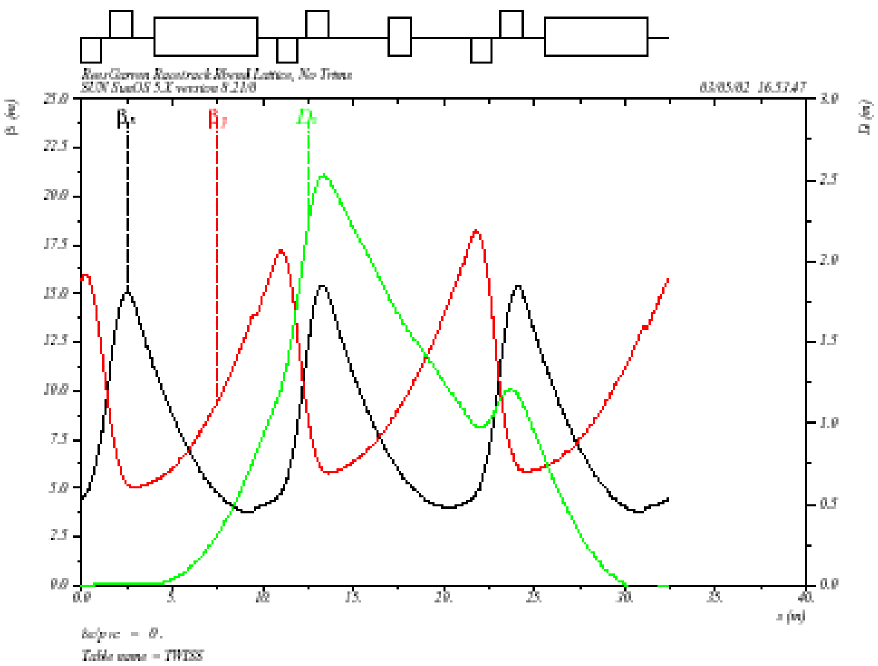
Layout



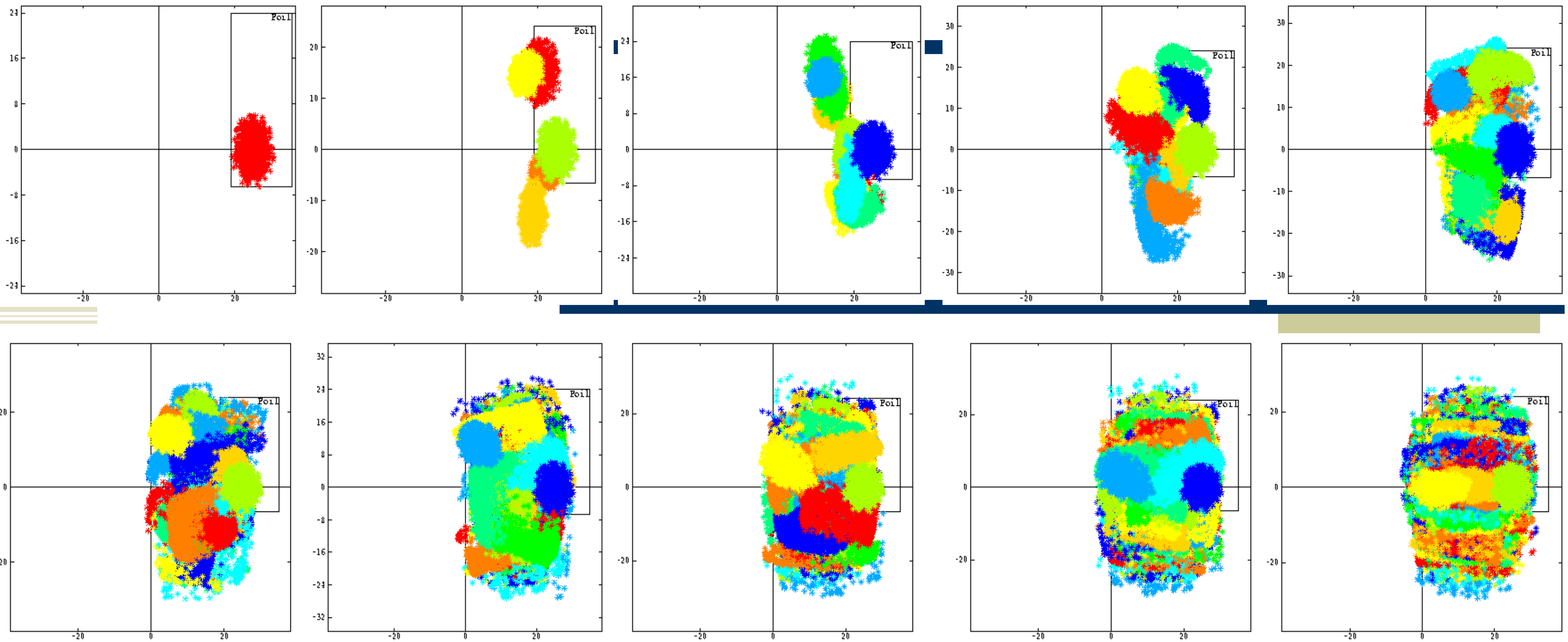
- Racetrack shape
- 2 arcs, 2 straights
- Each arc with 5 modules
- Each module with 3 doublet cells
- Straight sections for injection, extraction and RF
- Plenty space for diagnostics in the arcs and straights

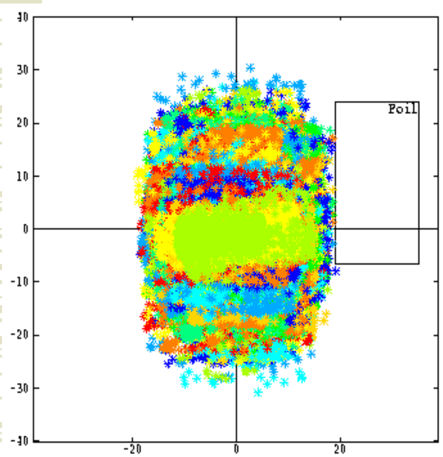
Lattice

Arc module



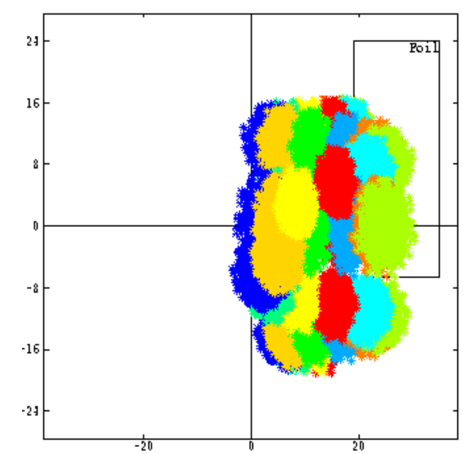
- Transition-free
- Dispersion-free straight sections
- Arc module: doublet 3-cell structure with a short dipole in the mid-cell
- Phase advance per module 0.8 and 0.6, respectively, in h- and v-plane



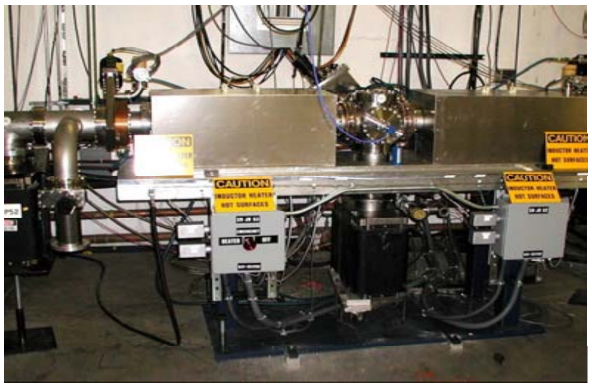


Space charge simulation

injected beam cross section at foil with space charge (zero space charge comparison to the right)



Inductive Inserts Experiment



- Two Fermilab modules installed in the PSR at LANL, increasing beam intensity significantly.
- Same modules will be tested in the Booster.

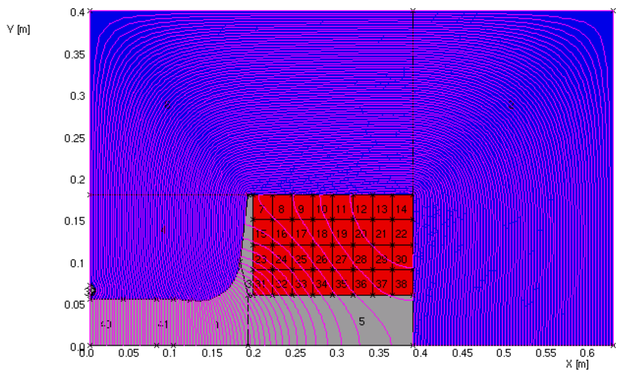
Booster RF Cavity Modification

(J. Reid)

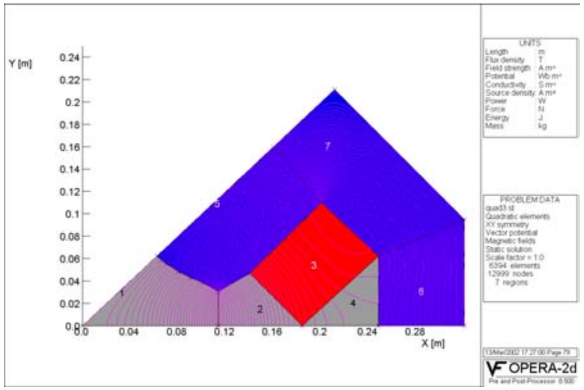
- Booster RF will be reused with modifications:
  - To increase the aperture from 2-1/4 in. to 5 in.
  - To increase the gap voltage from 55 kV to 66 kV.
- Two (out of 18) cavities have been modified and will be installed in the Booster.

Warm Magnets

Dipole

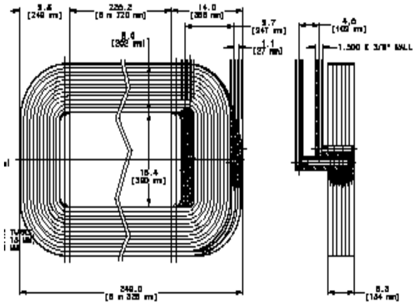


Quadrupole



Stranded conductors

Standard conductors with parallel connection



Superconducting Dipole Magnet (V. Kashikhin)

Main Issue:

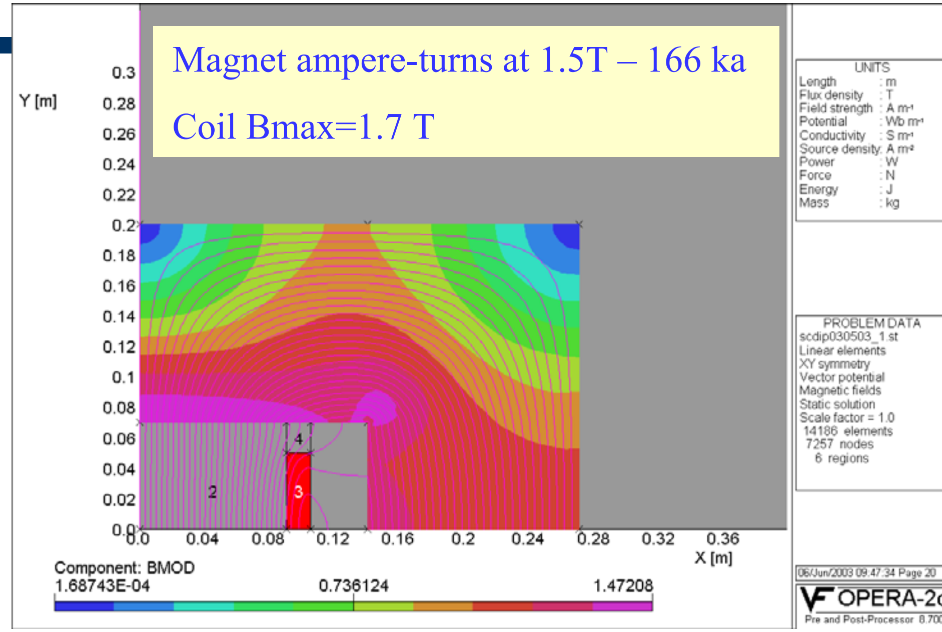
Superconducting cable and winding with low eddy current losses

Magnet Parameters:

Magnetic field	**1.5 – 3.0 T**
Frequency	**15 Hz**
Air gap	**100 – 150 mm**
Length	**5.72m – 2.86 m**
Superconductor	**NbTi/CuNi or HTS**
Iron/air core	**room temperature**
Cooling	**LHe forced flow**

Magnet ampere-turns at 1.5T – 166 ka

Coil Bmax=1.7 T



Superconductor AC losses < 3.3 kW/m^3 at 15 Hz and 0.5 mm dia.
Losses for 1.5 T magnet 1.2 W/m for NbTi/CuNi ALSTHOM superconductor with 0.16 um filaments

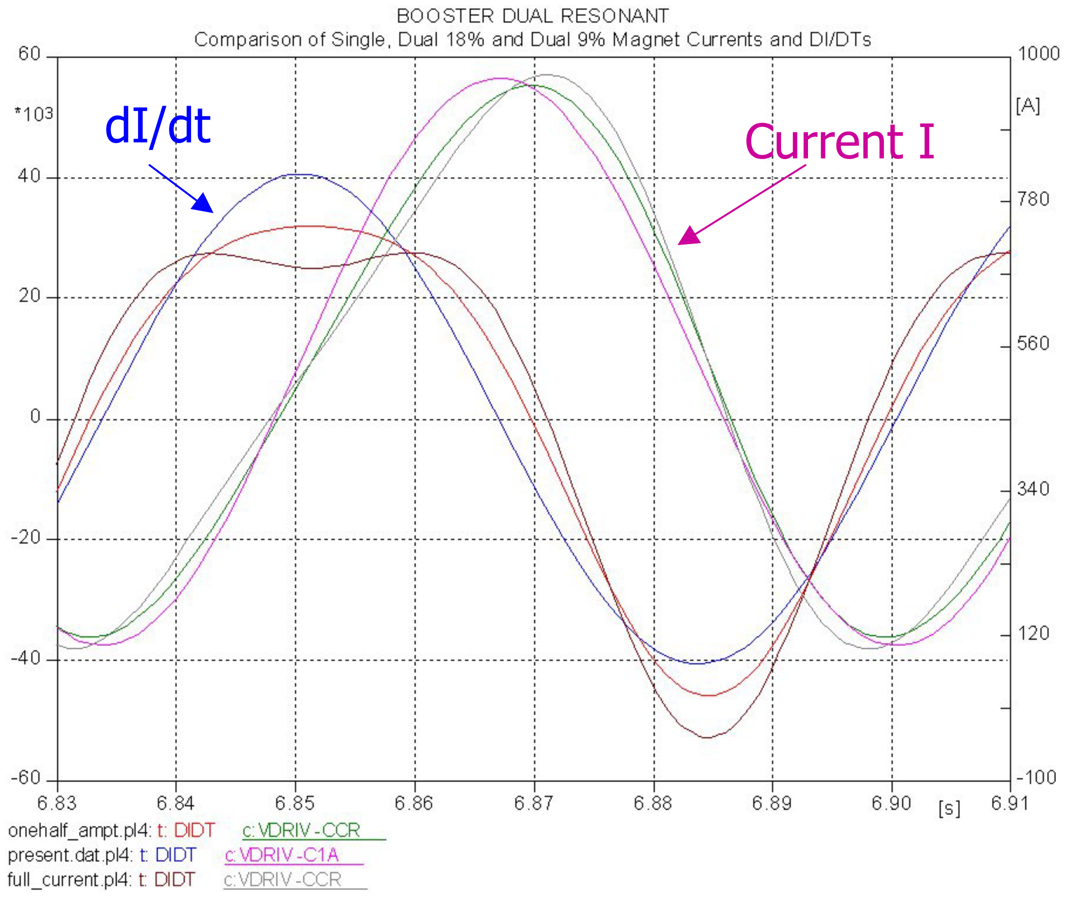
Hysteresis losses can be effectively reduced by decreasing a filament size to ~ 0.2 um

Eddy current losses effectively reduced by using high resistive CuNi matrix and small twist pitch 1.5mm for sub-wire and 6-8mm in 0.5mm wire.

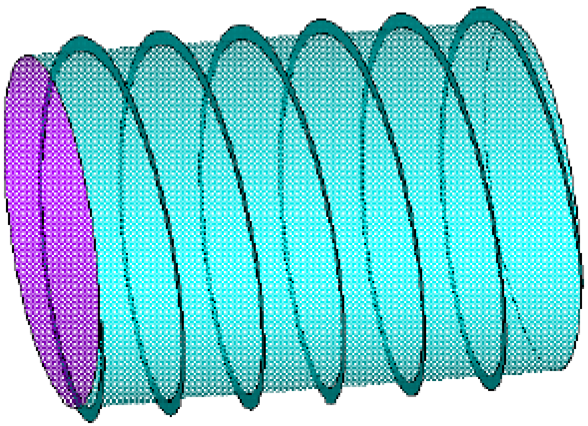
Careful optimization needed between SC cable, cooling pipes/channels and construction elements to reduce heat load up to reasonable value

Dual Harmonic Magnet Power Supply

(2nd harmonic component: 0%, 9%, 18%)



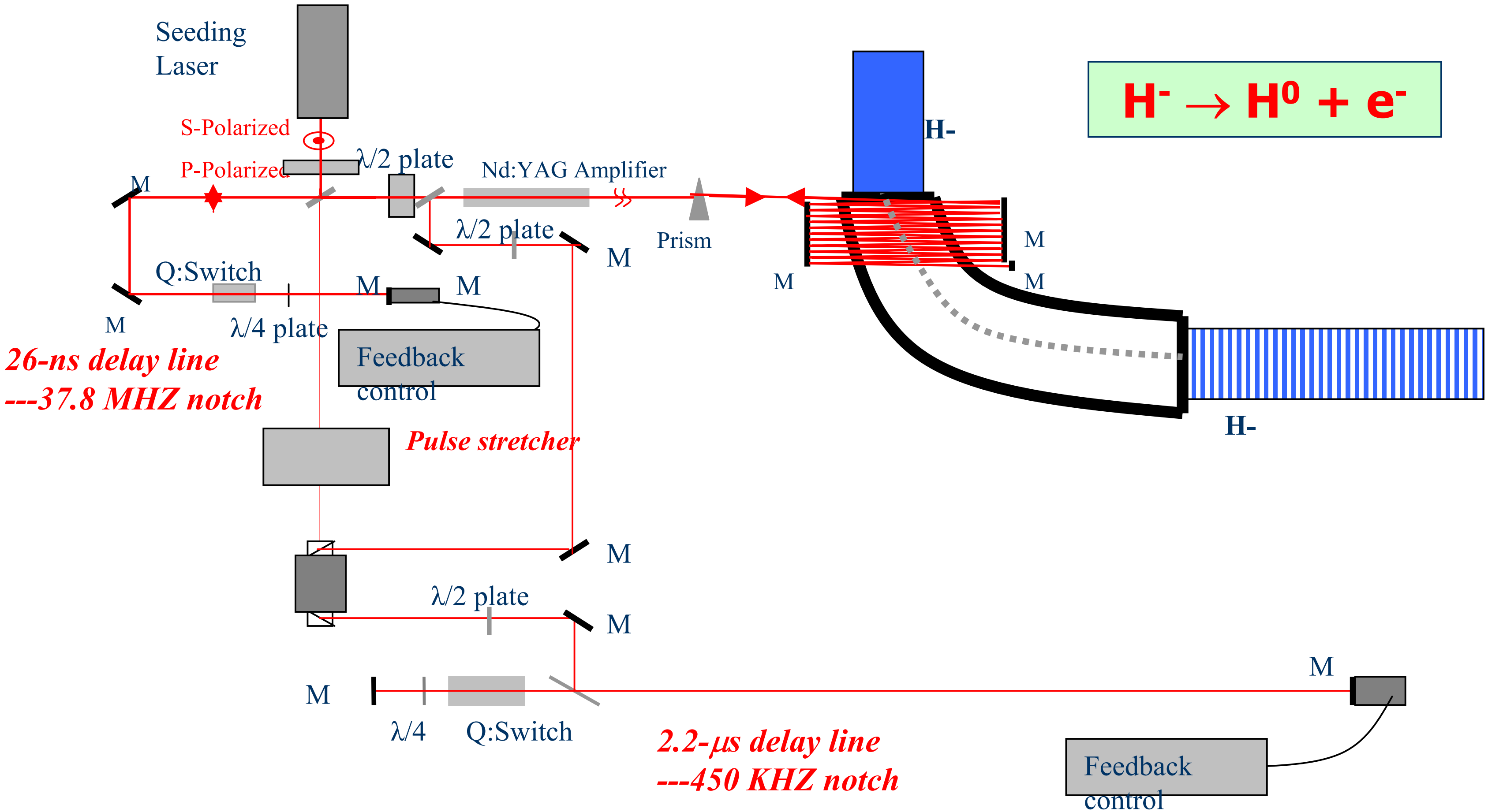
New Design of Beam Pipe



- New design: thin metallic pipe reinforced by spiral ribs
- Aperture: 4 in x 6 in oval
- Material: Inconel 718
- Wall thickness: 8 mils (0.2 mm)
- Spiral ribs: rectangular cross-section, width 28 mils, height 18 mils, 10 layers (total height 0.18 inch)
- Welding technique: laser deposition

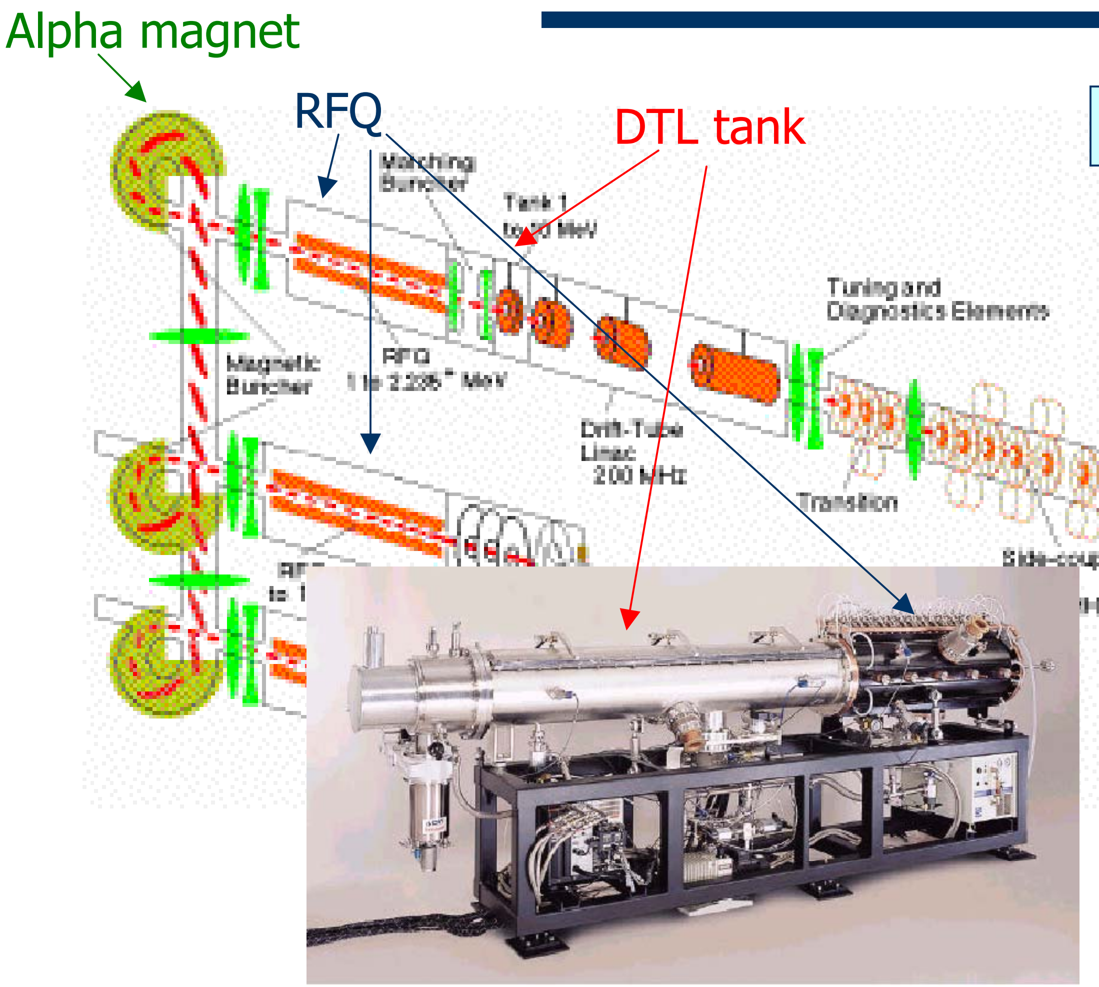
Laser Chopping

(R. Tomlin and X. Yang)

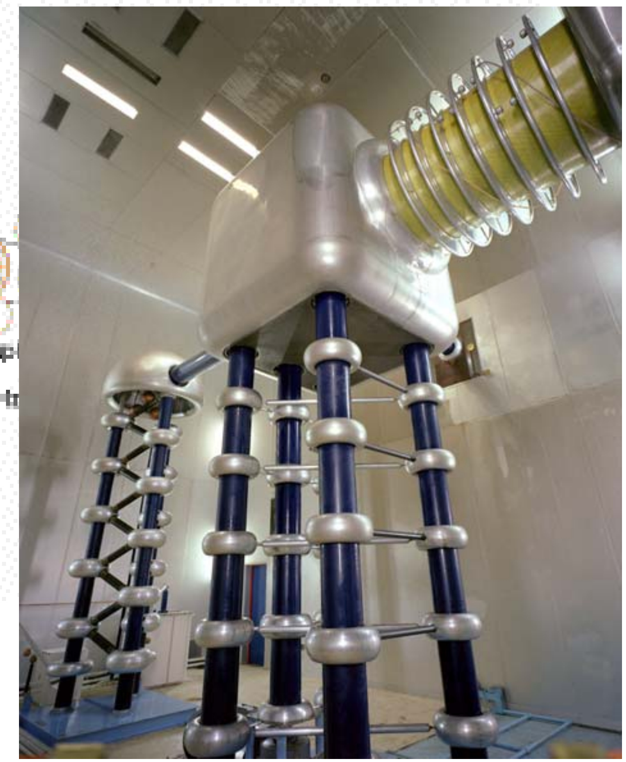


Collimators in Booster
(N. Mokhov, A. Drozhdin, P. Kasper et al.)

New Linac Front End



Old Cockcroft-Walton



(3) 2-MW Main Injector Upgrade

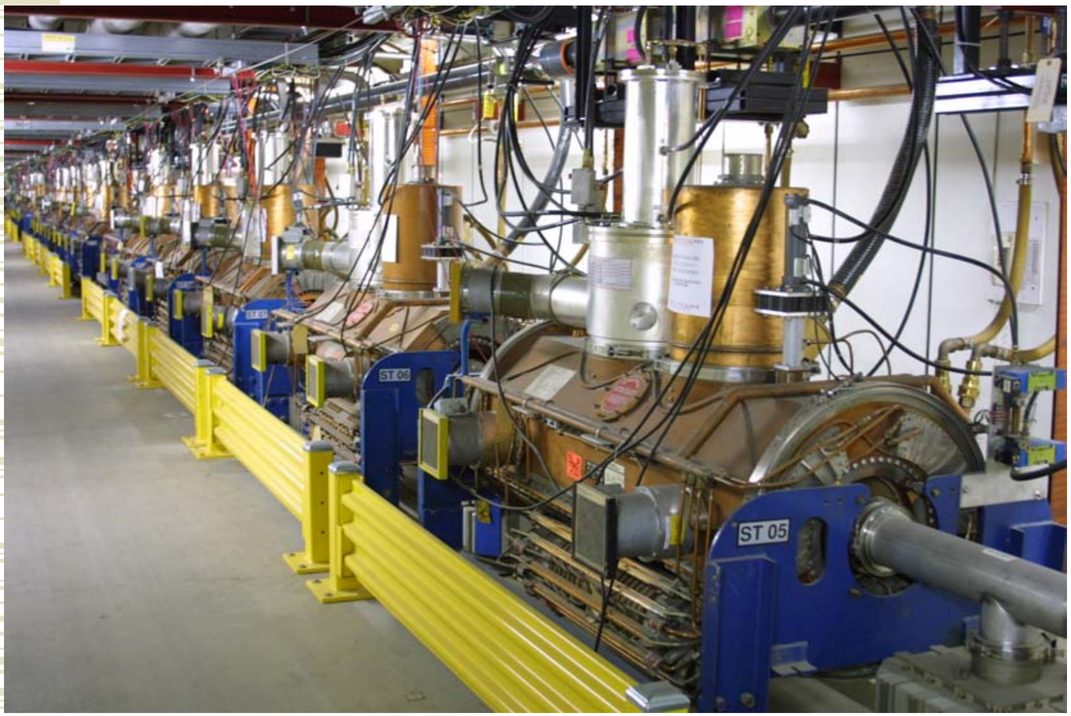
- Increase beam intensity by a factor of 5
- Reduce cycle time by 20%
- Increase beam power by a factor of 6

	Present MI	Upgraded MI
Injection kinetic energy (GeV)	8	8
Extraction kinetic energy (GeV)	120	8 - 120
Protons per MI cycle	3×10^{13}	1.5×10^{14}
Cycle time at 120 GeV (s)	1.867	1.533
Beam power (MW)	0.3	1.9

Main Injector Technical System Upgrades

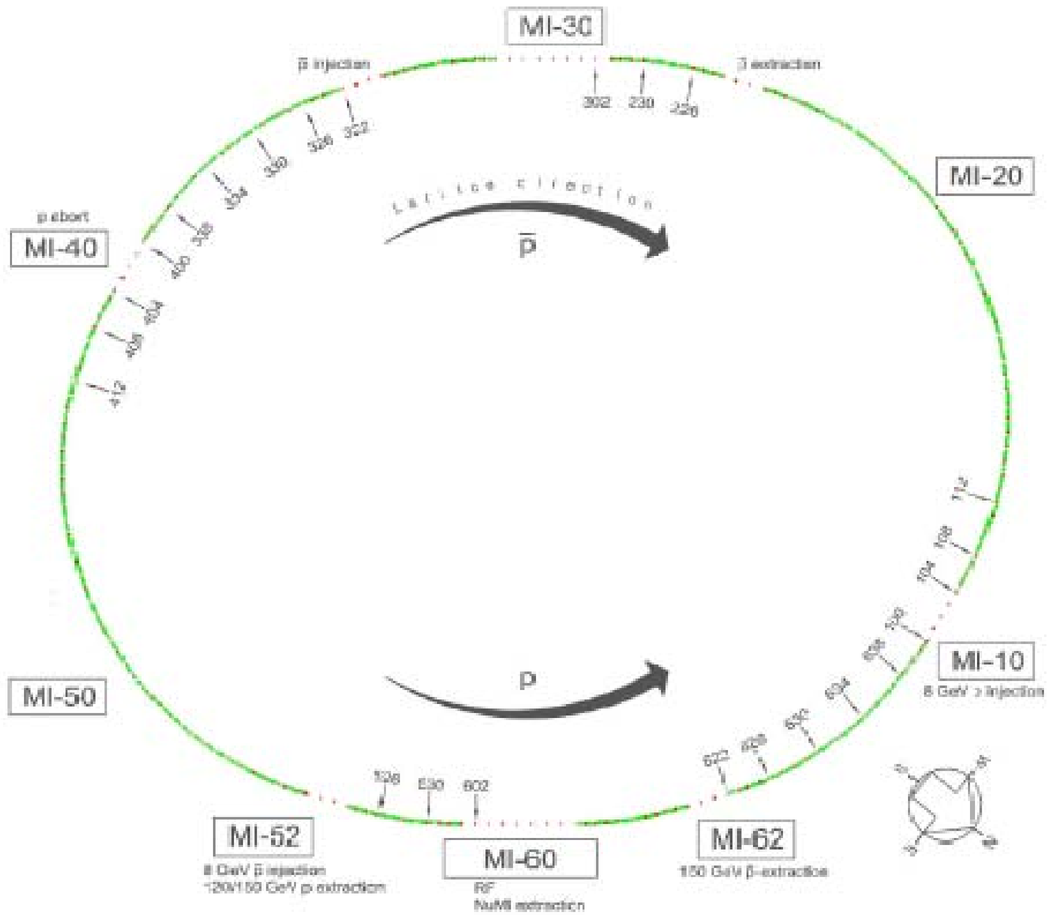
- One major upgrade:
  - RF system
- Several moderate upgrades:
  - Magnet power supply
  - Kickers
  - Feedback and damper
  - Beam dump
  - Cooling
  - NuMI and MiniBooNE beam lines
- Three new systems:
  - Gamma-t jump
  - Large aperture quadrupole (WQB)
  - Collimators
- No need for upgrade:
  - Magnet (But the recycled Main Ring quads may need to be replaced fro reliability reason)
  - Shielding
- Two additional upgrades for sc linac option:
  - 8 GeV H^- injection
  - MiniBooNE beam line

Main Injector RF System



- A major upgrade
- Number of power tubes will be doubled on each cavity
- More cavities to be installed.

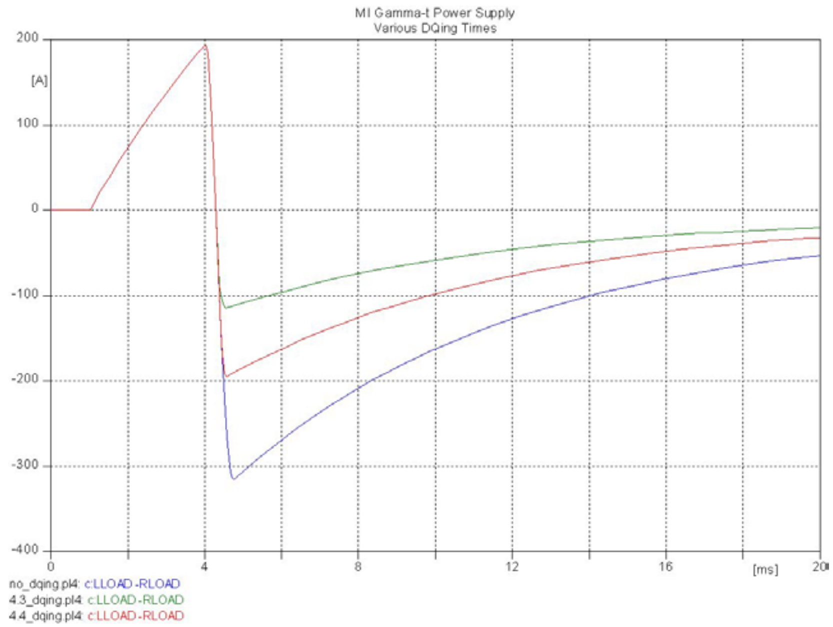
Gamma-t Jump System Layout



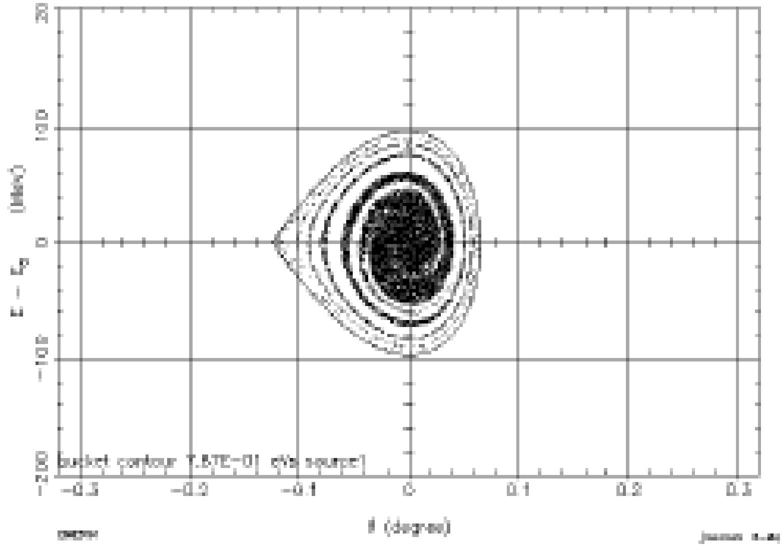
8 sets of triplet pulsed quads

Gamma-t Jump System (cont…)

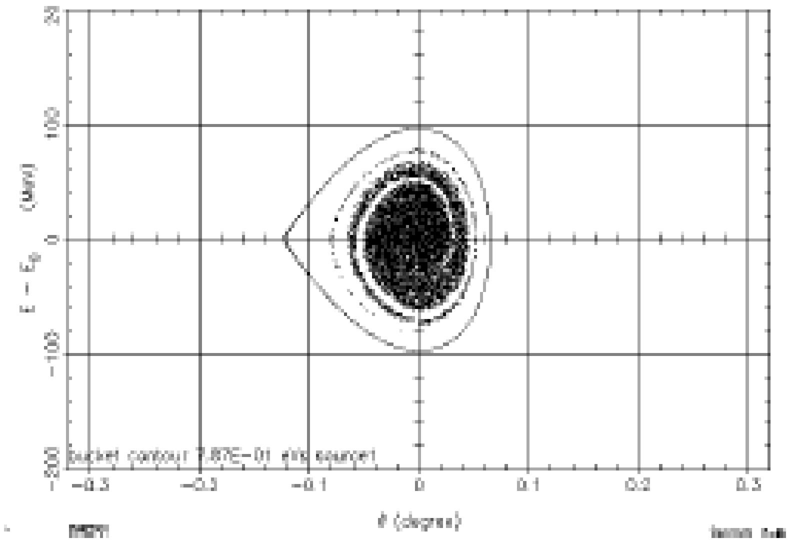
- A first order jump system with small dispersion increase (taking advantage of the dispersion free region)
- Design goal:
  - $\Delta\gamma_T = \pm 1$ within 0.5 ms
  - $d\gamma /dt = 4000$ 1/s
  - 16 times faster than the normal ramp (240 GeV/s)



Transition Crossing



Normal transition crossing



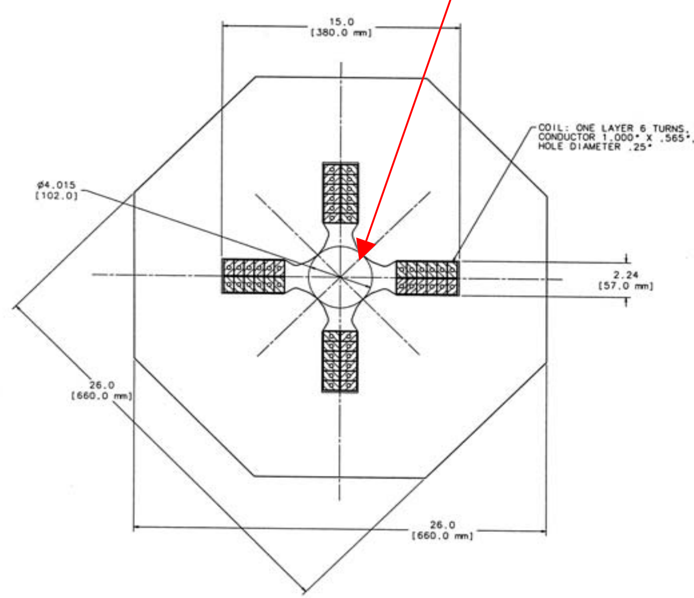
Transition crossing with γ_T jump

Large Aperture Quadrupoles (WQB)

- In injection and extraction sections, the quads near the Lambertson limit the physical aperture.
- They will be replaced by large aperture quadrupoles (WQB)
- Regular quad: 83.48 mm
  WQB: 102.24 mm

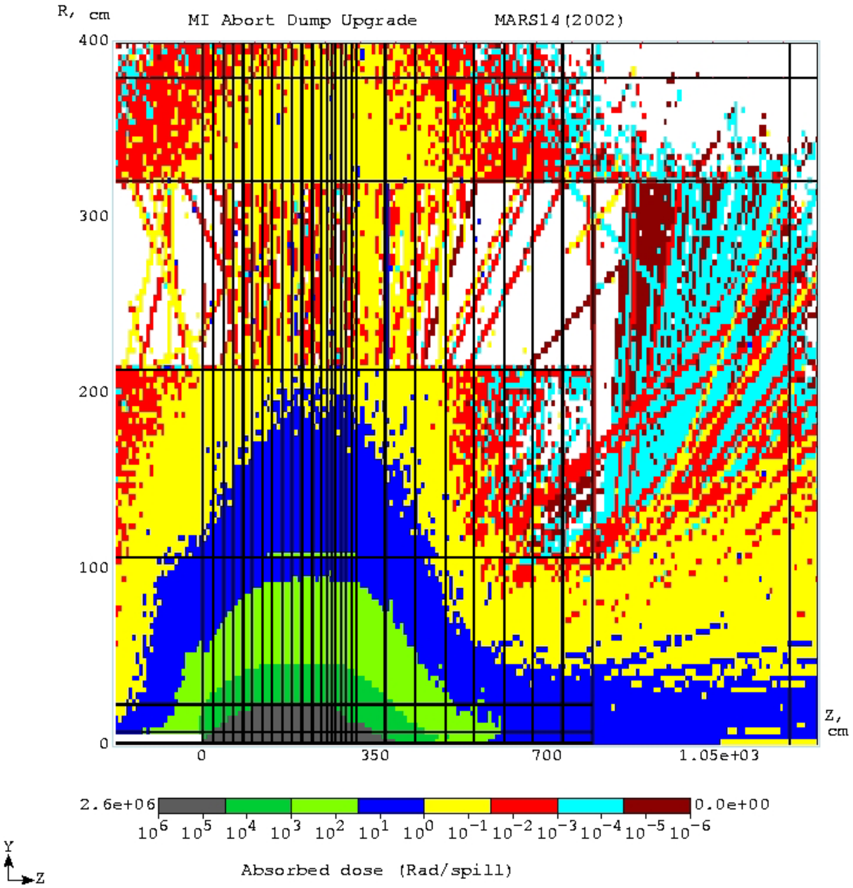
19.6 T/m

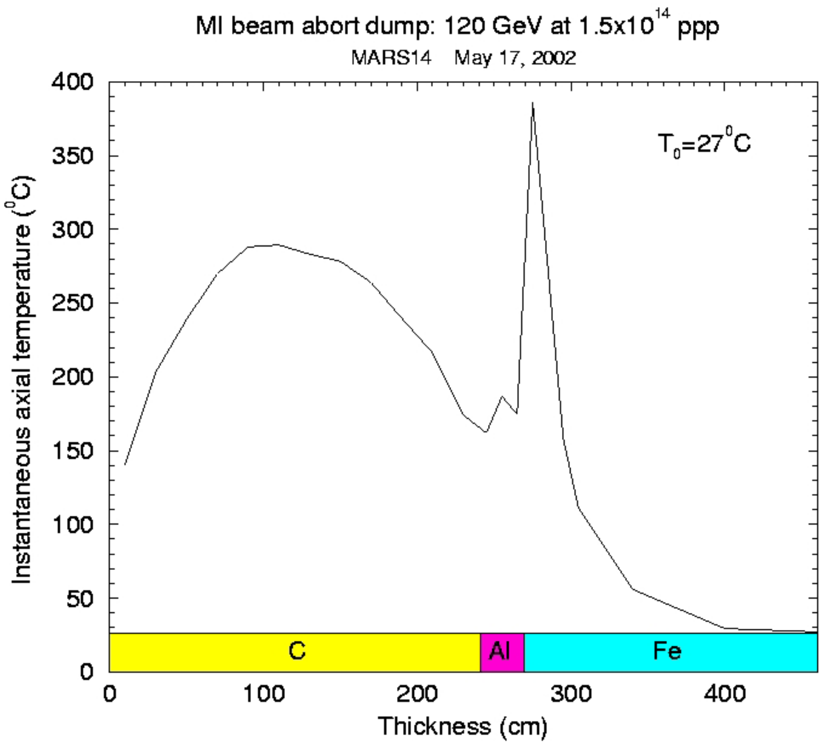
4 inch aperture



Abort System Upgrade

(N. Mokhov)





Summary

- Proton Driver is a special application of high power proton accelerators (HPPA) in high energy physics for providing super neutrino beams.
- Around the world, this is a very active field.
- In the U.S., the Department of Energy (DOE) has included Proton Driver in its 20-year strategic plan.
- At Fermilab, Proton Driver has been identified as a future construction project.
- This project includes a 0.5 MW Proton Driver and a 2 MW Main Injector for a total of 2.5 MW beam power in the range of 8-120 GeV.
- Documentation for DOE's CD-0 approval will be completed by the end of 2004.

Questions?