Accelerator Possibilities at FNAL

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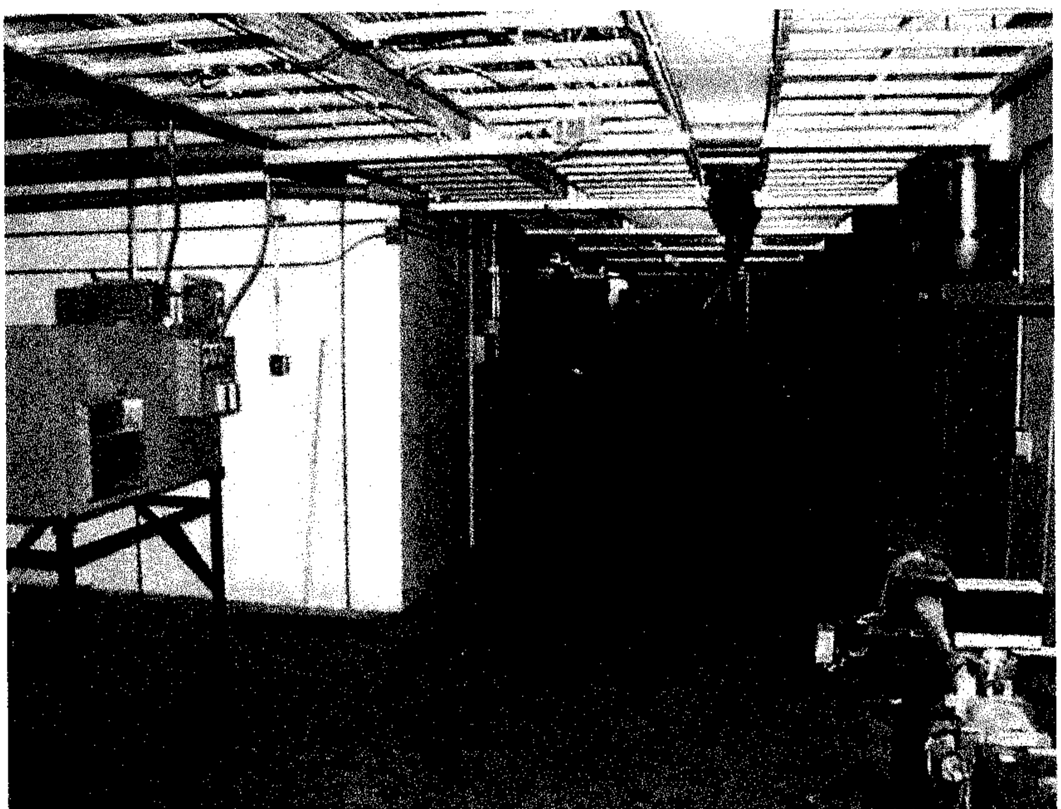


Note the empty cable tray above the tiny permanent magnets of the 8 GeV transfer line between the Booster and Main Injector. There is plenty of room for new initiatives at FNAL!!!!!

Non-Physics Missions for Pbars

Potential Medical Applications

* PET radioisotope production
* Antiproton Capture Therapy

Synergistic Technologies

PET Proof of Concept

*MC transport calculations indicate that $<10^{11}$ antiprotons are required to make the 15 mCi source for a ^{18}F treatment.

*(pbar,n) and (π,n) reaction cross sections need to be made on carbon, oxygen, nitrogen, and fluorine.

Synergistic Technologies

Phys. Med. Biol., 1985, Vol [illegible], No. 12, [illegible]. Printed in Great Britain

A measurement of the local energy deposition by antiprotons coming to rest in tissue-like material

A H Sullivan
CERN, Geneva, Switzerland

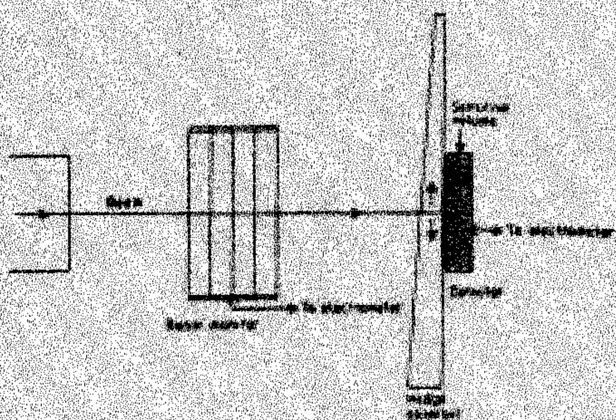


Figure 1. Diagram of the experiment. The beam passes through a monitor chamber and a variable absorber before entering the [illegible] chamber which measures the energy deposition by ionisation at the position of its sensitive volume.

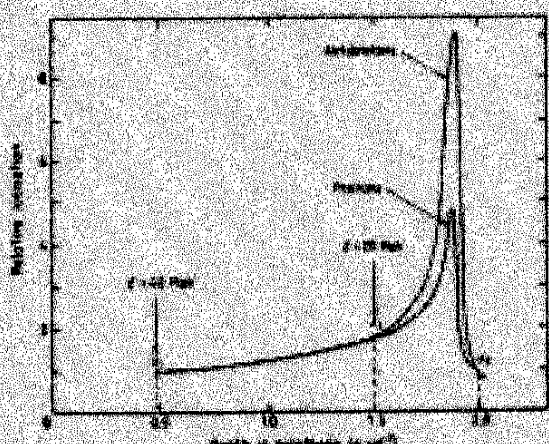


Figure 2. Variation of energy deposition by beams of protons and antiprotons with depth in [illegible]. Each curve normalised to 1 at a depth of 8.5 g cm^{-2}.

Conclusions

* Delivery of antiprotons to universities and medical centers would allow new research opportunities to be explored.
* Production of PET isotopes "at the patient's bedside" anywhere in the world appears feasible.
* A portable source of antiprotons may allow new cancer therapies to be developed.

Development of a low-energy source of antiprotons in the US will dramatically impact basic and applied research in this country.

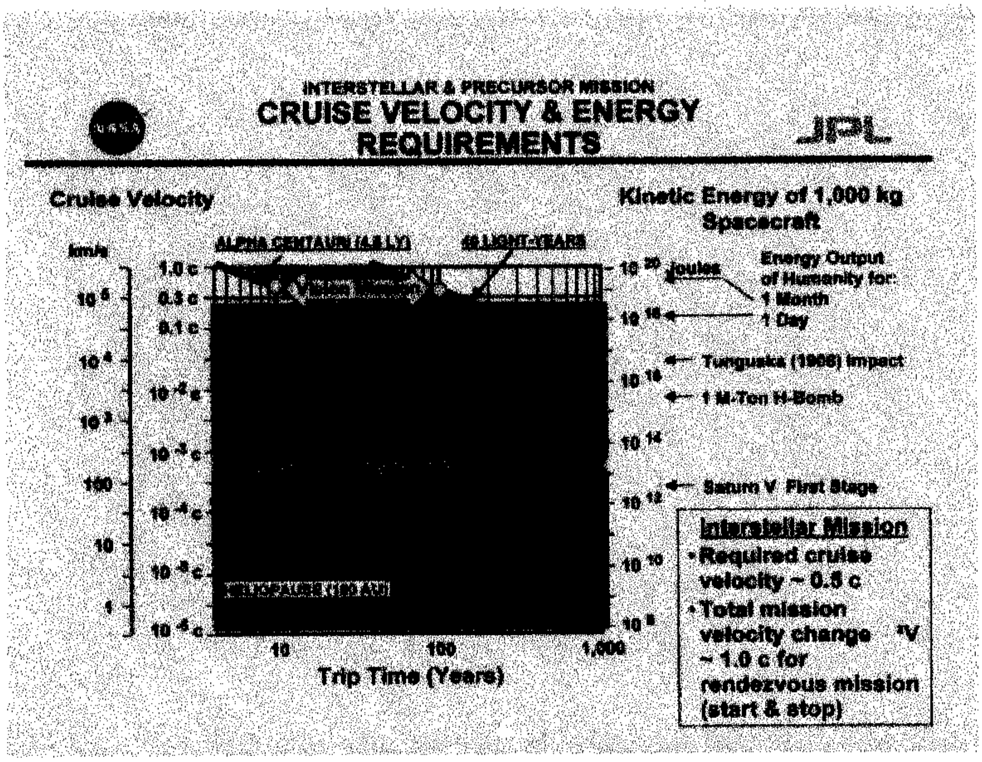
Synergistic Technologies

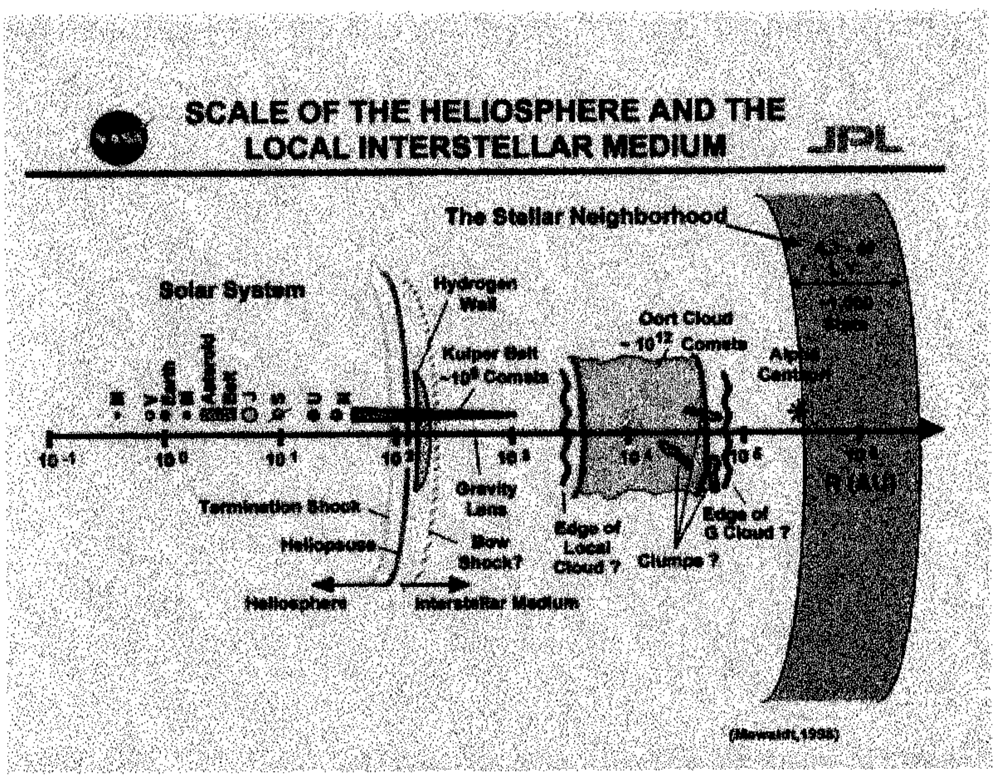
Space Transportation Research for Interstellar Missions

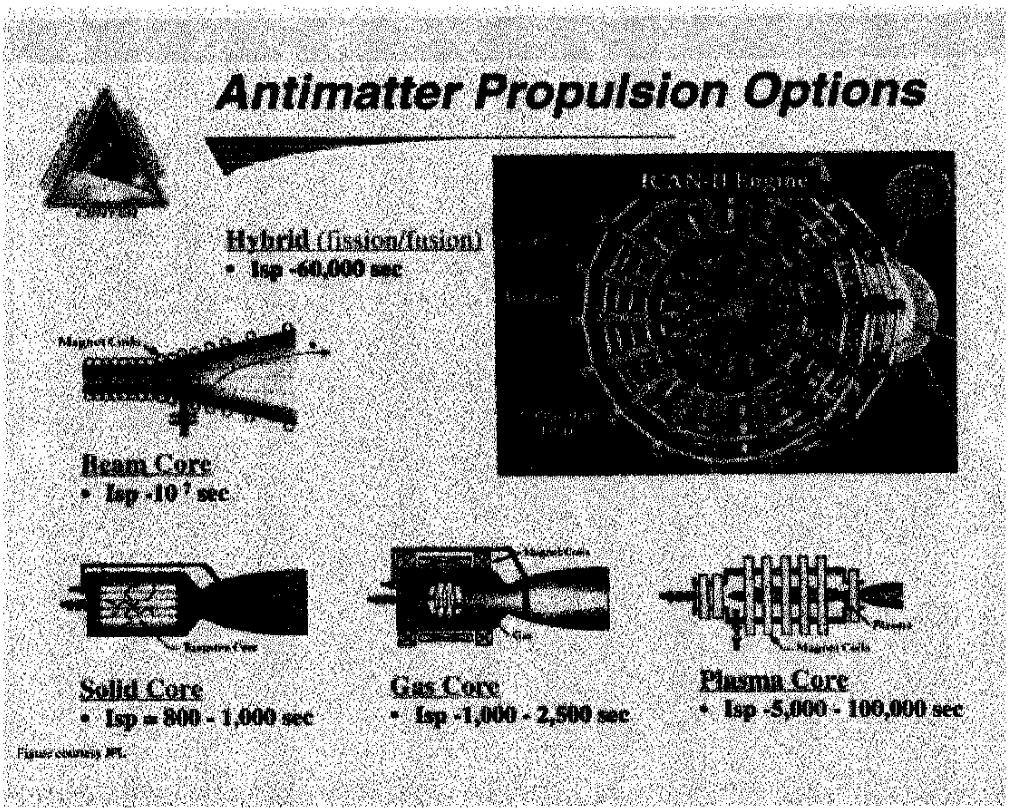
- **Matter-Antimatter**
  (Highest Energy Density Propellant)
  - Production, handling and storage
  - Converting energy to propulsion

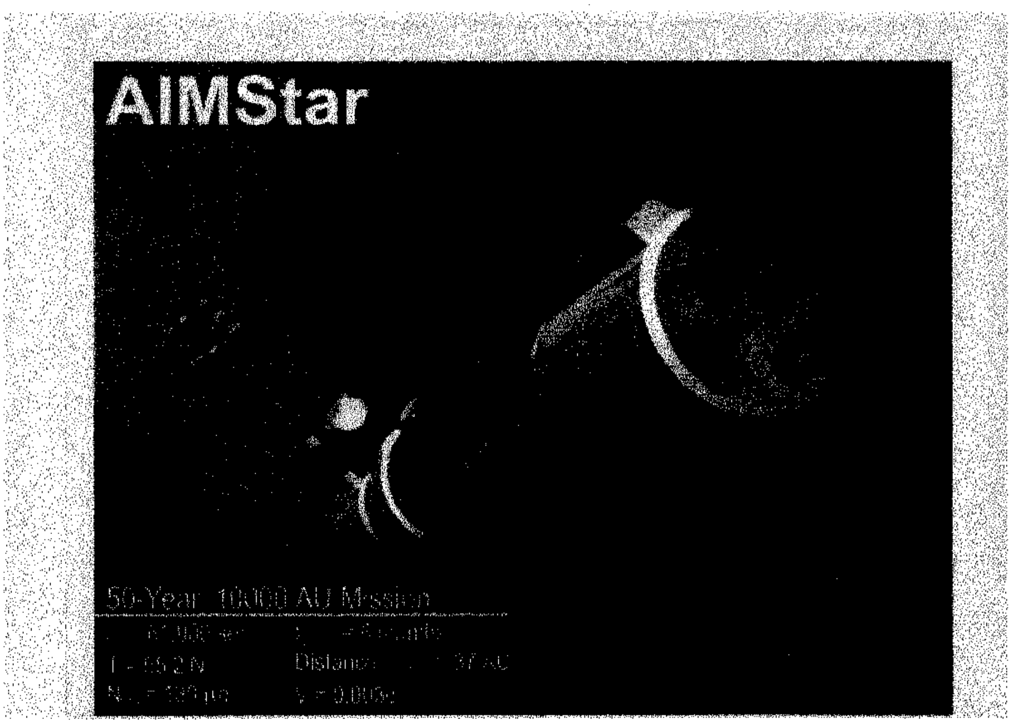
- **Fusion Ramjet**
  (Refueling on the Road)
  - H-H fusion
  - Large area magnetic scoops
  - "Drag-free" fusion

- **Beamed Energy**
  (Propellantless Propulsion)
  - Very high power lasers with large apertures
  - Precision pointing
  - Large, low density sails


INTERSTELLAR & PRECURSOR MISSION
CRUISE VELOCITY & ENERGY REQUIREMENTS
JPL
Cruise Velocity
Kinetic Energy of 1,000 kg Spacecraft
km/s
ALPHA CENTAURI (4.3 LY)
40 LIGHT-YEARS
1.0 c
0.3 c
0.1 c
Energy Output of Humanity for:
1 Month
1 Day
Tunguska (1908) Impact
1 M-Ton H-Bomb
Saturn V First Stage
10
100
1,000
Trip Time (Years)
Interstellar Mission
• Required cruise velocity ~ 0.3 c
• Total mission velocity change ~ 1.0 c for rendezvous mission (start & stop)

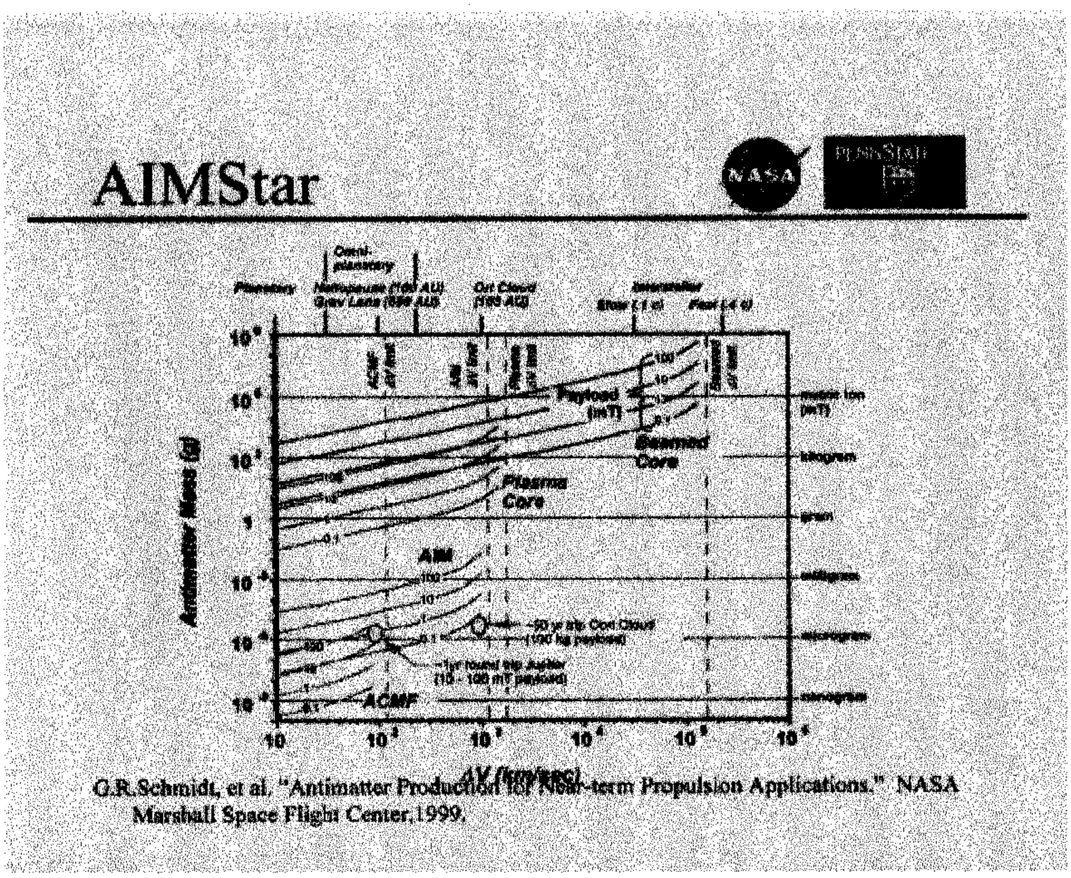

SCALE OF THE HELIOSPHERE AND THE LOCAL INTERSTELLAR MEDIUM
JPL
The Stellar Neighborhood
Solar System
Hydrogen Wall
Kuiper Belt
Oort Cloud
Gravity Lens
Termination Shock
Heliopause
Bow Shock?
Edge of Local Cloud ?
Clumps ?
Edge of G Cloud ?
Heliosphere
Interstellar Medium
R (AU)


Antimatter Propulsion Options
ICAN-II Engine
Hybrid (fission/fusion)
• Isp ~60,000 sec
Magnet Coils
Beam Core
• Isp ~10 ⁷ sec
Tungsten Core
Magnet Coils
Gas
Plasma
Magnet Coils
Solid Core
• Isp = 800 - 1,000 sec
Gas Core
• Isp ~1,000 - 2,500 sec
Plasma Core
• Isp ~5,000 - 100,000 sec
Figure courtesy JPL


AIMStar
50-Year 10000 AU Mission
Distance

1 μg = 6E17 pbars

Future FNAL Stacking Rate: 1E12 pbars/hr
= 6E15 pbars/year
= 10 nanograms/year



PENN STATE/NASA ANTIPROTON PENNING TRAP PROGRAM

- **MARK I Portable Penning Trap (JPL sponsorship)**

1. 10^{10} antiprotons
2. 0.4 T permanent magnetic field
3. 1 kV potential well
4. 10^{-10} torr vacuum
5. 4 day equivalent antiproton lifetime in portable mode successfully demonstrated with H- ions (1999)
6. Trap moved (5/2000) to NASA MSFC for more tests

- **HiPAT Portable Penning Trap (NASA MSFC sponsorship)**

1. 10^{12} antiprotons
2. 4 T superconducting magnetic field
3. 20 kV potential well
4. 10^{-12} torr vacuum
5. 400 day lifetime expected
6. Tests in progress at NASA MSFC Propulsion Research Center

Present "Available" FNAL Stacking Rate
(assuming ~10% tax on HEP luminosity):

3E11 pbars/day
in 3 transfers/day @ 1E11 pbars/transfer

08/14/00 MON 11:51 FAX 630 840 6311 FERMILAB 13 NORTH 009

Overview of FNAL Options

• Decelerate in the Accumulator Ring

This is the present means by which antiprotons are decelerated at Fermilab. Because the Accumulator has a peak momentum of 8889 MeV/c, in principle it should be able to decelerate antiprotons down to 500 MeV/c. In addition, it already has cooling systems built into it.

Unfortunately, there are two problems with regularly decelerating antiprotons in the Accumulator during Tevatron Collider operations. First, deceleration in the Accumulator is slow and very people intensive. Second, it is completely destructive to any remaining antiprotons.

• Decelerate in the Booster Ring and Linac

This was the original scheme for decelerating antiprotons which was proposed 1993. It has many technical problems, such as the fact that the Booster RF cavity bias power supplies do not source reverse current, and hence the cavities do not track the beam frequency during deceleration. As usual the Devil is in the details!

• Decelerate in the Booster Ring and the IUCF Cooler

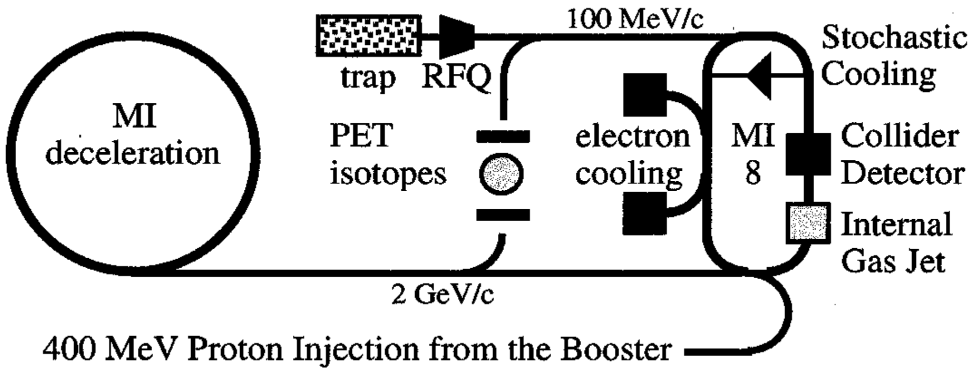
The Booster (with the modifications mentioned above) is capable of decelerating an antiproton beam to a kinetic energy of 400 MeV. A better and more efficient method for further deceleration is to copy (or borrow) the IUCF cooler ring, which has a peak energy very close to 400 MeV. At present there is a proposal to have the IUCF staff study deceleration in their ring using protons, to understand the efficiencies of electron and stochastic cooling, and to understand the issue of space charge dominated beam storage.

• Deceleration in the Main Injector to 2 GeV/c

This is an active program at Fermilab. The idea is to use the great magnetic field quality in the new Main Injector to decelerate the antiprotons to 2 GeV/c, which is thought to be the lowest momentum that antiprotons can be brought down to with full efficiency.

Further deceleration in a low energy ring would then take place to a momentum of 100 MeV/c. Already the magnet power supplies and RF control system have been shown to track a deceleration ramp. The next studies will attempt to actually decelerate beam.

Perhaps the best selling point of the Main Injector deceleration approach is the fact that it can be implemented adiabatically at low incremental costs.

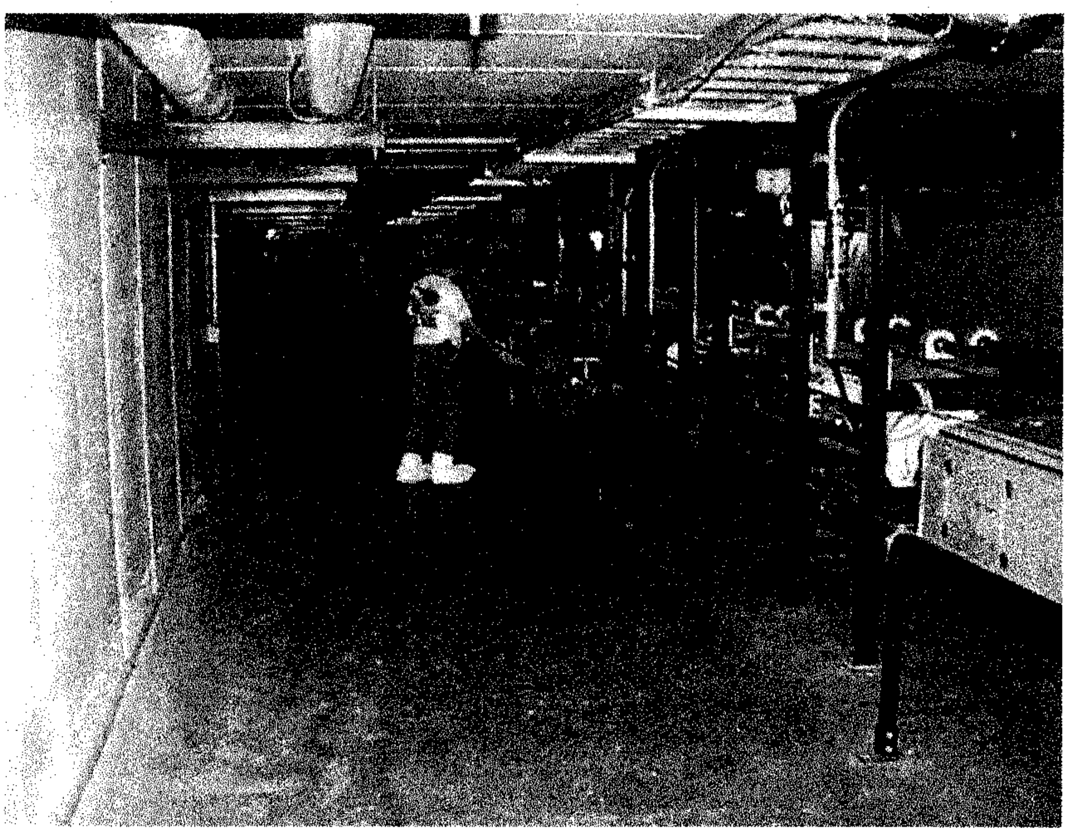


Parameter	Injection	Extraction
MI Momentum (MeV/c)	8889	2000
MI Kinetic Energy (MeV)	8000	1271
MI8 Ring Momentum (MeV/c)	2000	100
MI8 Ring Kinetic Energy (MeV)	1271	5.3
MI8 Ring Relativistic Velocity	0.905	0.106
MI8 Ring Relativistic Energy	2.35	1.0057
Pre-Trap RFQ Mom. (MeV/c)	100	30
Pre-Trap RFQ KE (MeV)	5.3	0.5
Pre-Trap RFQ Rel. Velocity	0.106	0.032

Staged MI Deceleration Goals

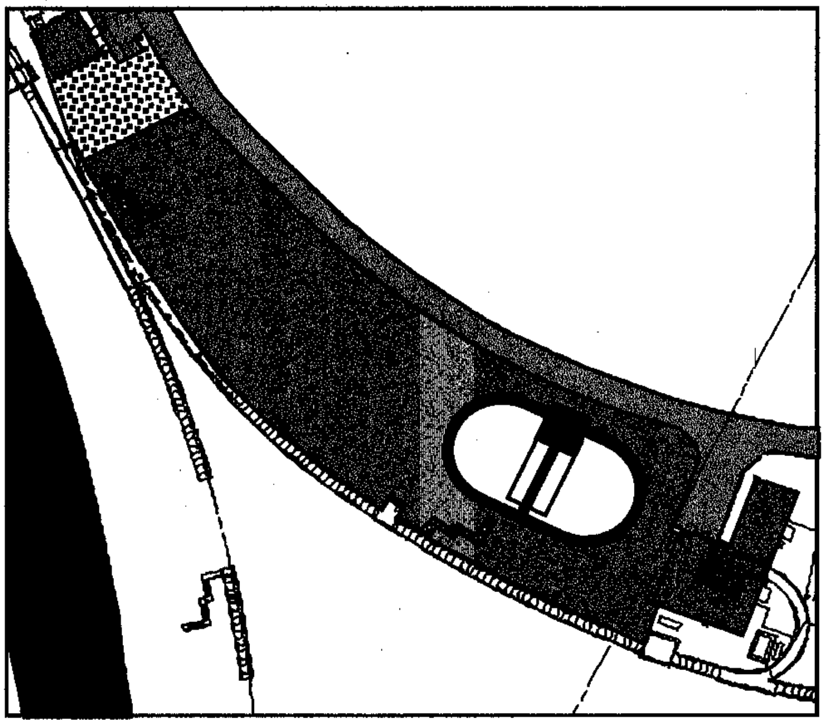
Step 1: Decelerate Protons in the Main Injector
Goal: Attain a proton momentum of 2 GeV/c

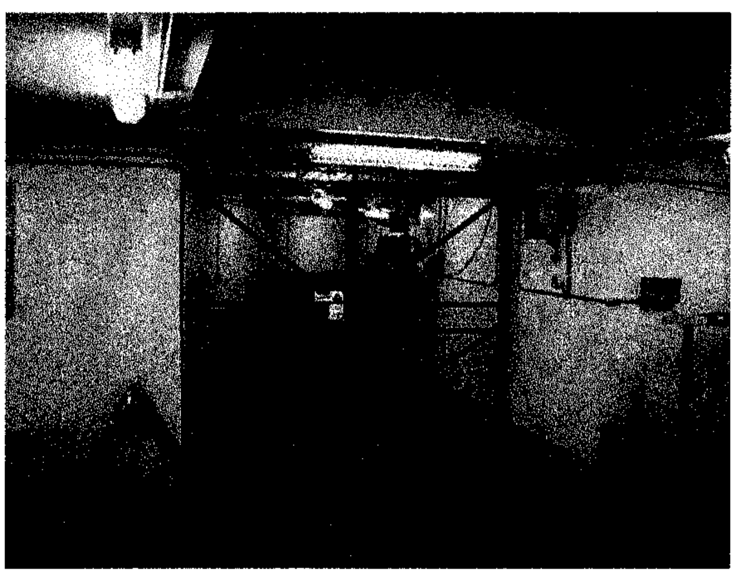
Step 2: Extrtact Decelerated Antiprotons at MI-10
Goal: Use dE/dx to slow antiprotons for PET isotopes using a site riser for sample insertion.



Step 3: Build Antiproton Transfer Line to MI-8 Drop

Goal: Use dE/dx to slow antiprotons for trap studies, such as antihydrogen production studies.





Step 4: Build 400 MeV Line from Booster to MI-8 Drop

Goal: Further trap studies & test detector test beams.

Step 5: Build MI-8 Ring and commission with Protons

Goal: Circulate antiprotons in collision with gas jet, collide protons and antiprotons to generate hyperons and look for heavy quark states, further decelerate antiprotons before dE/dx slowing for higher efficiency PET isotope production and initial fuel production for NASA.

Conclusions

A staged plan has been proposed in which each intermediate step represents an adiabatic expansion of capabilities for modest cost and effort.

The first step is to decelerate protons to 2 GeV/c in the Main Injector. There is every reason to believe that the Main Injector is already capable of decelerating with only very modest hardware modifications and some significant software extensions.

We have already taken a first stab at understanding the stability of the power supplies. After a couple of hours of work, power supply stability has been demonstrated.

A study occurred in which the RF frequency was monitored in order to watch the effect on the low level RF system and control system timing hardware. So far so good.

Given that a single 20 second cycle in the timeline has no effect on Tevatron commissioning while E835 stores are in progress, we are requesting Main Injector study time between now and the September shutdown.