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1275 Roosevelt Rd., Suite 103, West Chicago IL, 60185
www.hbartech.com

Antimatter Driven Sail for Deep Space Exploration

Dr. Steven D. Howe (showe@hbartech.com)
Dr. Gerald P Jackson (gjackson@hbartech.com)

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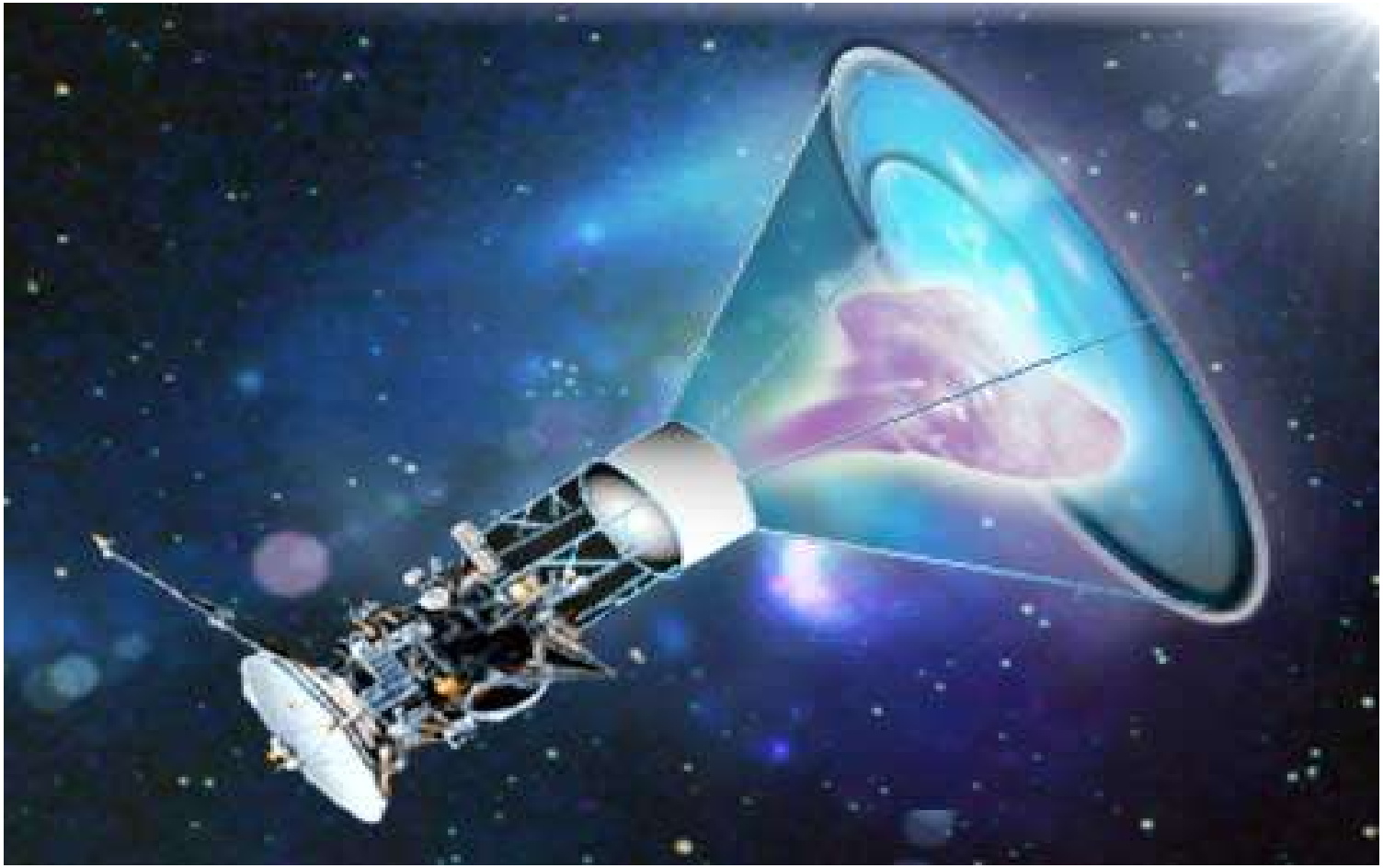
Concept Overview



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Antiproton Annihilation

- On average, the annihilation produces three 400 MeV charged pions and three gamma-rays (from neutral pion decay).
- On average, 1.25 pions are absorbed by the nucleus, causing the nucleus to recoil and fragment, carrying on average 150 MeV.
- For heavier elements, annihilation causes fission: Homeland Security!
- In living tissue, neutron annihilation usually produces PET isotopes.

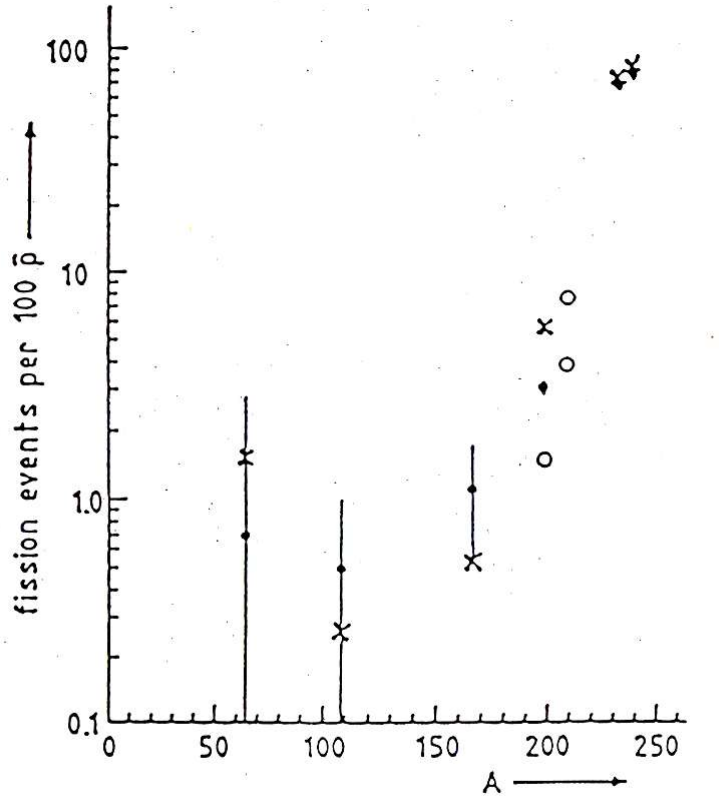

Fig. 3. Absolute fission probabilities for Cu, Ag, Ho, Au, ^{208}Pb, Bi, Th and U targets [6].

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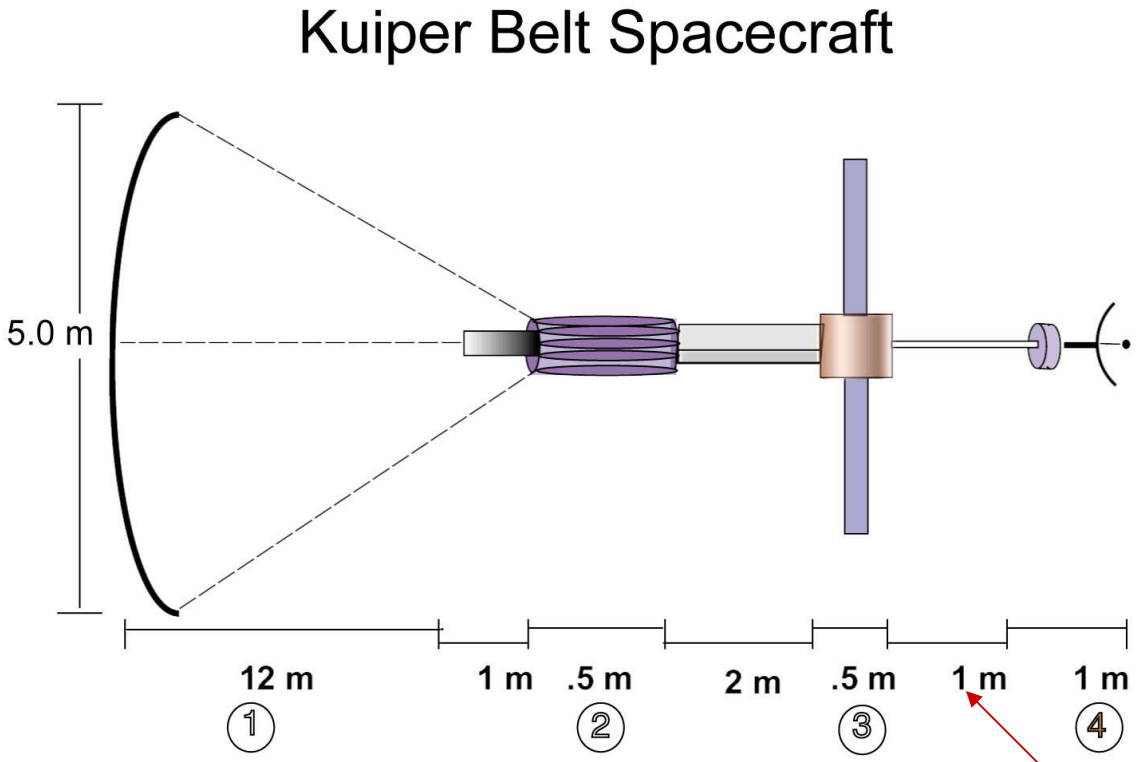
Hbar Technologies Architecture



- Antiproton fission produces two products, (roughly Pd-111) each with near 1 MeV/amu
- A particle with 1 MeV/amu has a velocity of around $1.38X10^7$ m/s
- Thus, an Isp of over 1 million seconds is possible

For radiation reduction, this could be a kilometer tether

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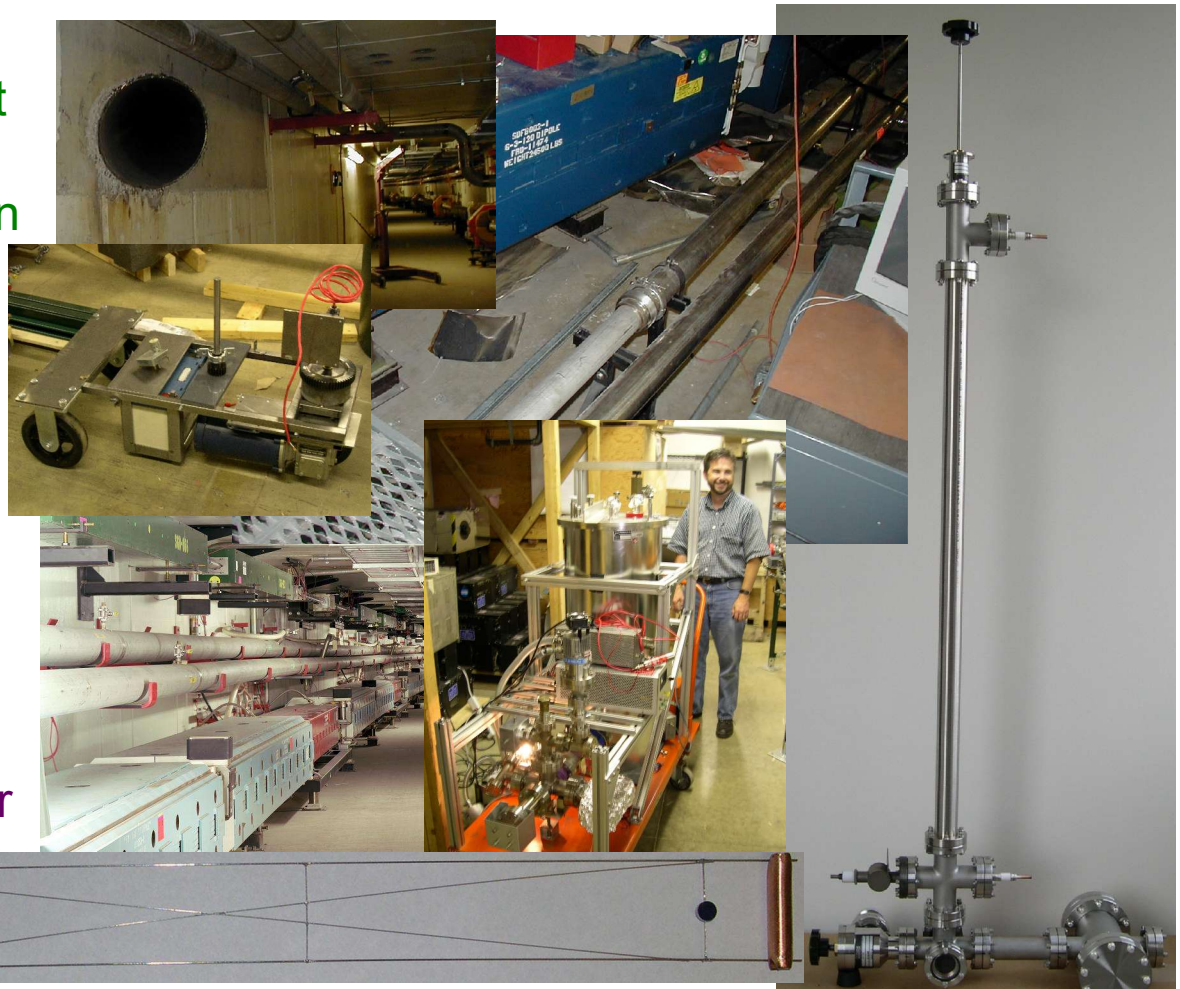
Phase II Role in Overall Enterprise

- No one grant or institution is ready to devote sufficient resources to develop antimatter-based propulsion concepts.
- To date we have funded theoretical and experimental development efforts through a tag-team approach between private investors, DOE, NIAC, the NASA Marshall Space Flight Center Propulsion Research Center, and Hbar Tech.



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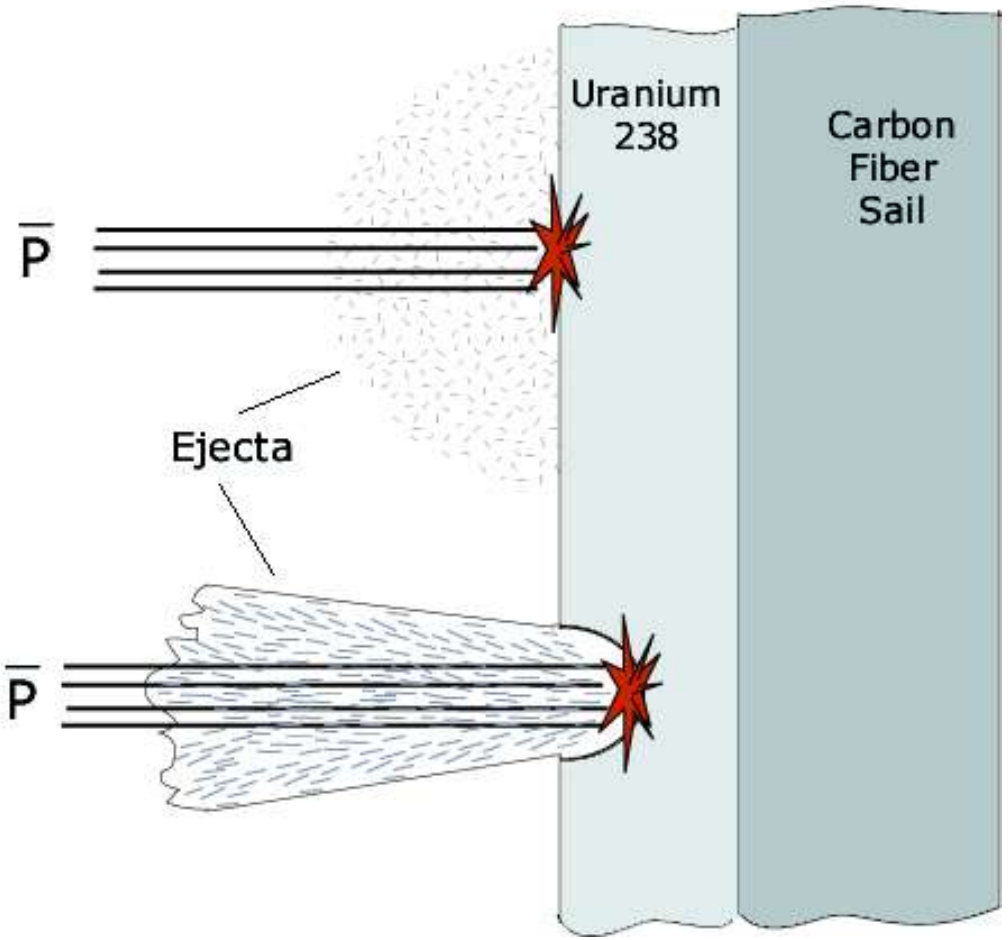
Phase II Goal: Propulsion Test



- Sail concept may have the ability to adjust the average exhaust velocity by varying the incident pbar energy or sail material.
- Depositing the antiproton deep into the uranium leads to multiple atom ejection, maybe resulting in increased thrust and reduced Isp.
- Initially, the momentum is transferred to the ship by the ingoing fission fragment.
- What is the momentum contribution from the multi-atom burst?
- Mechanism(s) causing burst is not verified or quantified.

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Fermilab Overview

- The Fermi National Accelerator Laboratory, also called Fermilab or FNAL, is sited 40 miles west of Chicago in Batavia, Illinois.
- Fermilab's mission is to perform high-energy particle physics, and currently operates the highest energy accelerator in the world (the Tevatron proton-antiproton collider)
- The Main Injector accelerates protons to 120 GeV and directs them into the antiproton production target.
- The Antiproton Source accumulates and cools the antiprotons.

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Antiproton Production @ Fermilab

- Present: 10^{11} antiprotons/hour for 4500 hours per year.
- Present: 27.4 M$/year for purchase of all antiprotons.
- Basic Research: At present, research that is published in peer-reviewed journals are the subject of collaborative agreements wherein antiprotons are provided free.
- Availability: Fermilab has discussed giving us approx. 1% of the antiproton production rate (2.4×10^{10}/day), though for good reason this number can be increased.
- Deceleration and Extraction: Antiproton pulse intensities between 10^9 and 10^{11} can be decelerated and extracted.

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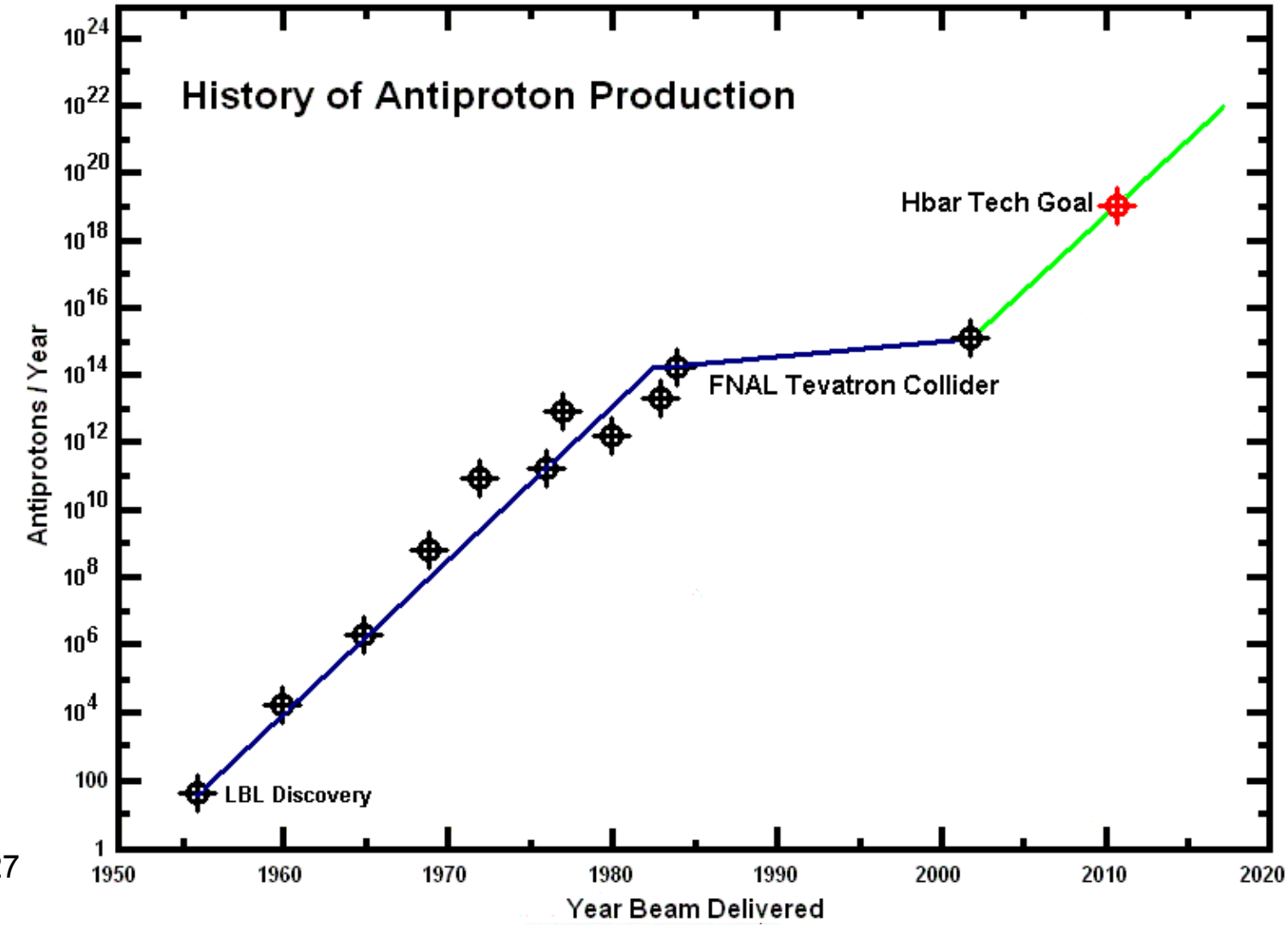
Antiproton Production History



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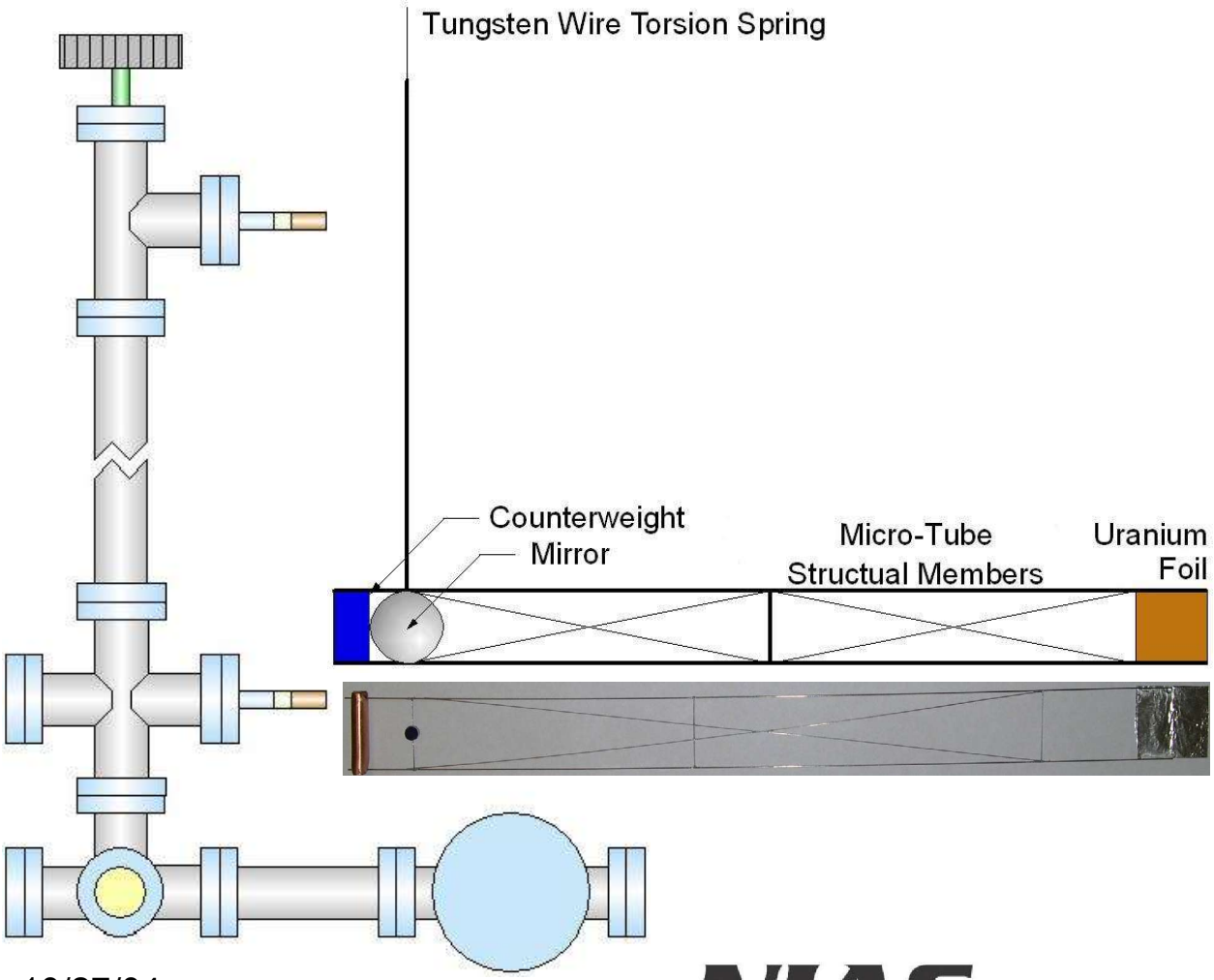
Torsion Balance Thrust Test



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Torsion Balance Parameters

Parameter	Value
Uranium Foil Thickness (mils)	1
Uranium Foil Dimensions (in.)	1
Uranium Foil Mass (g)	0.19
Length of Torsion Balance Arm (in.)	1 / 11
Torsion Balance Arm Total Mass (g)	2.6
Total Torsion Balance Rotation Inertia (g-cm^2)	147
Tungsten Wire Diameter (mils)	0.5
Torsion Balance Spring Constant (g-cm^2/sec^2)	.016
Oscillation Period of the Balance (sec)	605
Initial Velocity Imparted to Uranium Foil (cm/sec)	0.0001
Laser Spot Deflection at 2 m (mm)	0.6

The number of antiprotons on target is 10^9

Assumes no uranium emission

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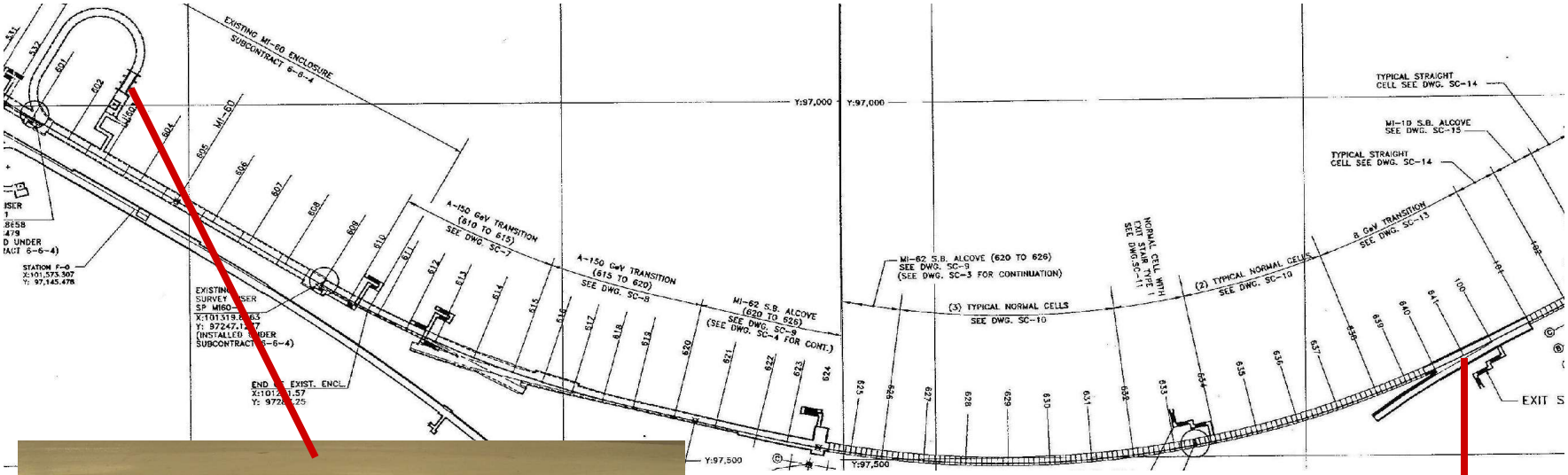
Antiproton Extraction Layout



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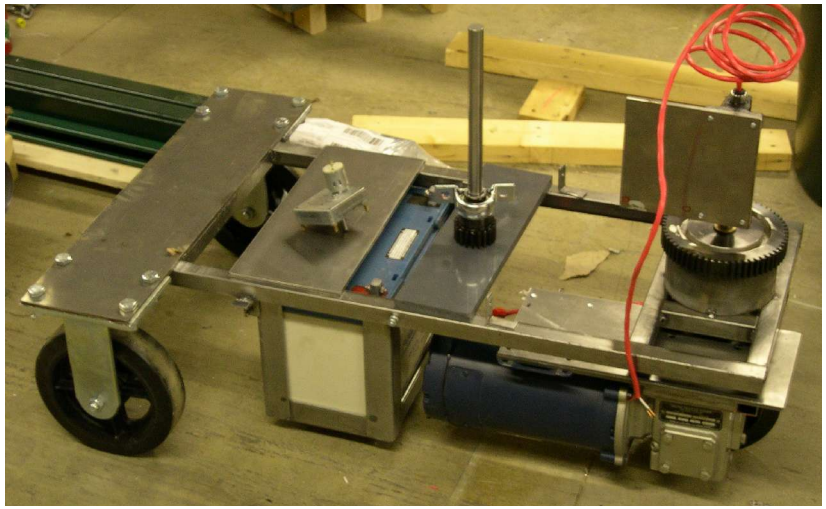
Robotic Accessibility

- The only feasible option for accessing Fermilab antiprotons on the time and financial scale of this Phase II award is to construct a robot that can carry the torsion balance to a convenient extraction point in an existing beam line.
- Robot fabrication is complete, though tinkering is ongoing. Fabrication of magnets and other ancilliary hardware is mostly complete, again with ongoing tinkering taking place.



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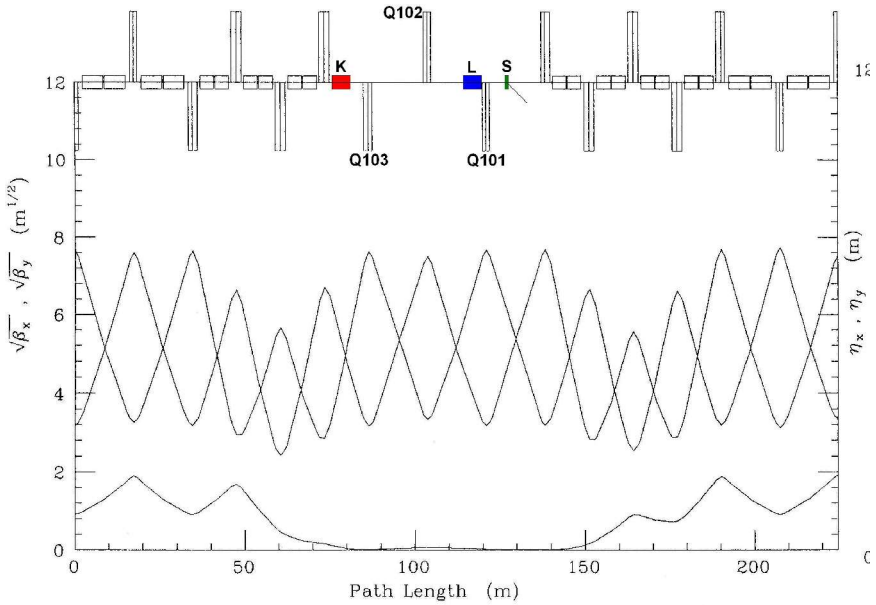
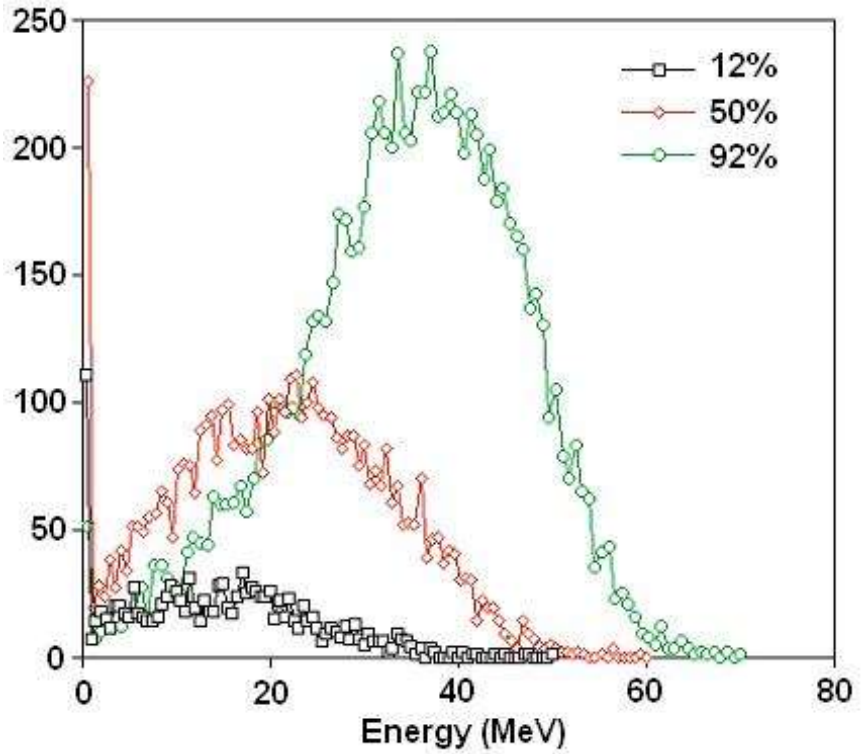
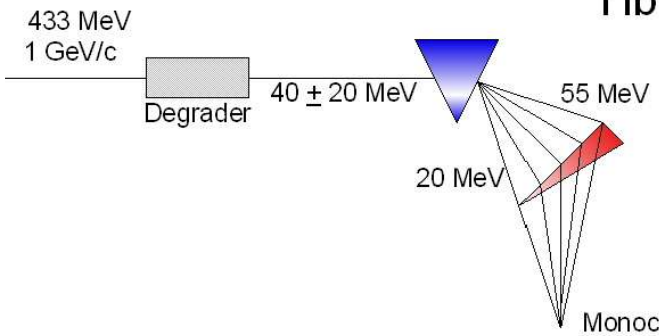
Antiproton Extraction





Hbar Tech Line



The Main Injector can decelerate part of the way down, but a degrader brings down the beam energy by an extra factor of 10x

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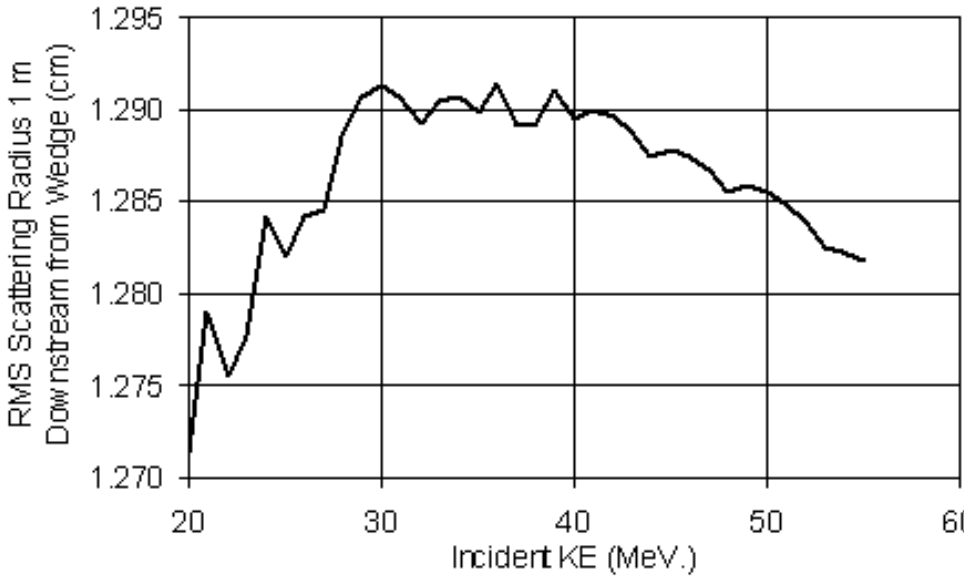
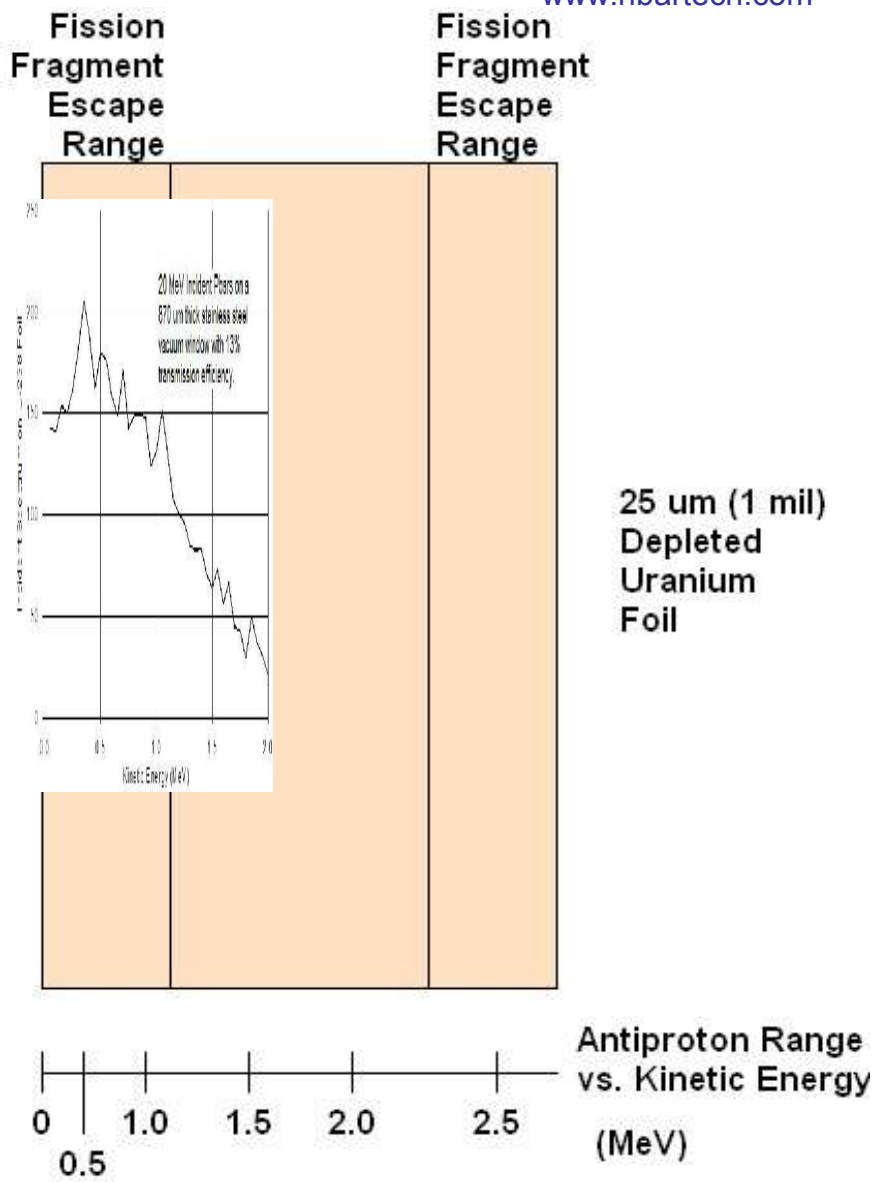
Antiproton Targeting

The 20 MeV antiprotons pass through a 860 um stainless steel vacuum window to reach the torsion balance.





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Antiproton Detection

- An important way to reduce costs is to measure the antiproton trajectory, transverse size and shape, and energy distribution with innovative and inexpensive detectors.
- One of the effects of antiproton annihilation against a nucleus is the occasional creation of positron emitting isotope.
- In the case of fluorine, the annihilation against a neutron generates fluorine-18, which has a half life of 110 minutes.
- Exposing a Teflon cylinder (CF_2) to antiprotons will produce a fluorine-18 with roughly 16% efficiency.
- Once the cylinder is exposed, a local hospital PET scanner will be used to measure the above antiproton beam properties.

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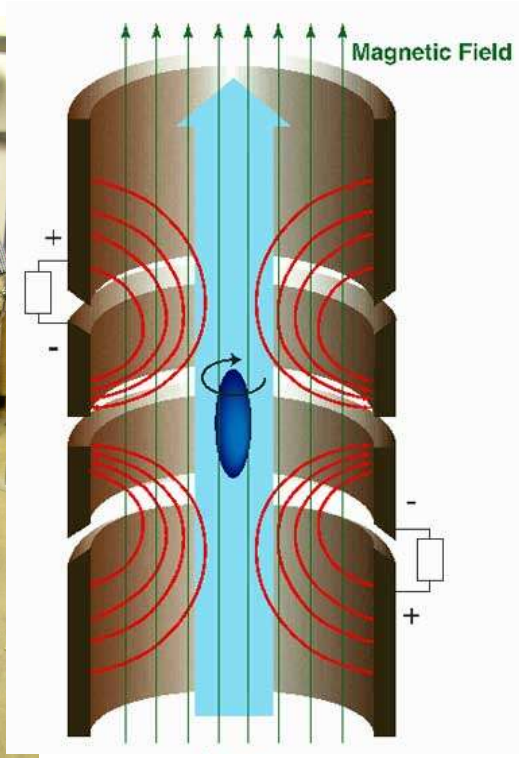
Upgrade beyond Phase II



The picture to the left shows the “Mark I” portable NASA MSFC Penning trap at the Hbar Tech fabrication facility just outside of Fermilab.

MSFC is prepared to send us the next generation HiPAT trap in the near future.

By filling these traps first and extracting the cooled beam, we will be able to measure the thrust from purely surface annihilations.