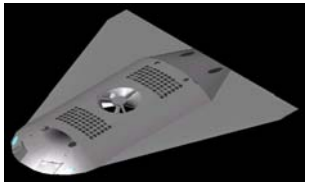
Propulsion And Power With Positrons

NIAC Fellows Meeting

24 Mar 2004

- Ken Edwards
- Director, Rev Mun IPT
- Munitions Directorate
- Air Force Research Laboratory

The Vision



“Write the Vision.
Make it plain upon tablets. So he may run that reads it. If it seems slow; wait for it will surely come. It will not delay”
Habakkuk 2:2

“For where there is no vision, the people perish”
Proverb 29:18

“But we go exploring anyway despite our fears and our ignorance. Despite voices that argue that what we know is enough.”
from Introduction of “To Seek Out Life” By
A Andreadis

Revolutionary Munition Conops
24/7 Battlespace Dominance

Satellite Reconnaissance

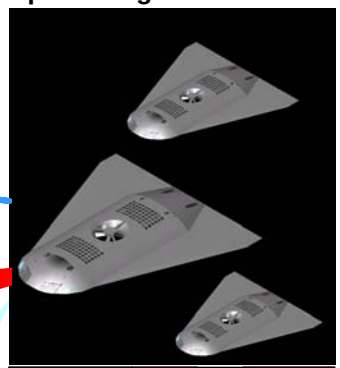
Airborne Operations Controller

Sensor Craft

Stealthy Forward Air Controllers (FACs)

UAV Reconnaissance

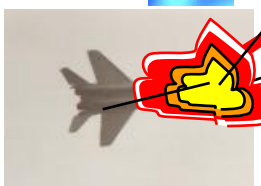
Loitering Omni-role Weapon
Fixed & Bunkered Targets
Ground Mobile Targets
Aircraft and Missile Targets
Space Targets



Special Operations Ground Troop FACs

Battle Field Internet Provides 24/7 Situational Awareness And Search And Destroy Capability

Space Targets



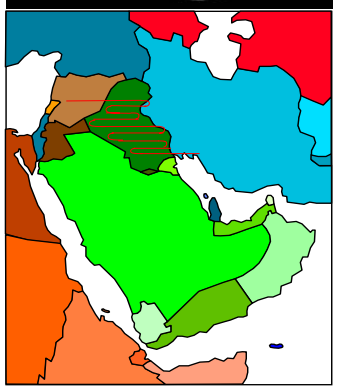
Air Targets

Ground Targets/Underground Targets

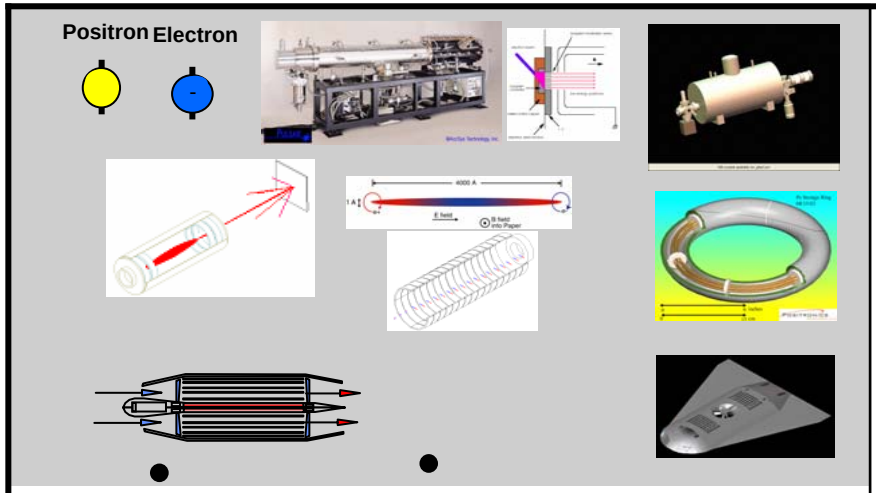
SEARCH

DESTROY

BOMB
IMPACT
ASSESSMENT



Positron Energy Conversion Quad



Technology: ***Positron Energy Conversion-***

Anti Matter Annihilation Energy From Annihilation of Positrons - 180 Mega-joules Per Microgram

One Gram Equals 23 Space Shuttle Fuel Tanks Of Energy

Single-stage- To- Orbit, Long Endurance , Earth to Mars Propulsion

Options - No Nuclear Residue

Risk: High Risk - Production, Moderation, Confinement, Conversion

Application(s):

Tremendous Energy Density for Long Term Continuous 24/7 Atmospheric Propulsion

Mars Exploration Propulsion

CONUS Based Surveillance of Worldwide Scenarios

Players: None but US So Far

Programmatics:

- ***Current AFRL/MN Program: Coordinated Group of SBIRS and Revolutionary Technology Programs and AFOSR Request to Produce, Moderate, and Store Positrons and Positronium Atoms***
- ***Cost to Demo (Lab-$5m, Field- $90M, or Prototype-$2B)***
- ***Time to Demo (Lab-2 Years, Field - 8 Years, or Prototype -15 Years)***

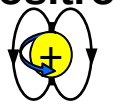
Introduction: What Is Antimatter?

For Every Fundamental Particle in Nature, There Is an Antiparticle of Same Mass & Opposite Charge

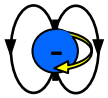
Discovery

- Antimatter Predicted (Dirac in 1928)
- Positively Charged Electrons (Positrons) Discovered (Anderson in 1932)
- Positronium (Ps) Discovered (Deutsch in 1951).
- Antiprotons Produced in Synchrotron (Chamberlain & Segre in 1953)
- Positrons Stored in “Penning” Traps (in 1985)

Positron

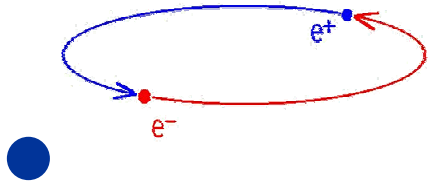


Electron



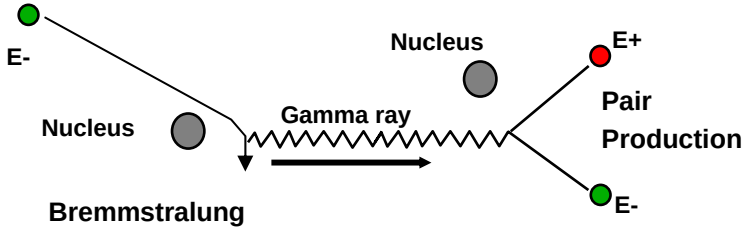
Positrons Annihilate Each Other and Produce Two 511 Kev Gamma Rays

Positronium



http://lacebark.ntu.edu.au/j_mitroy/research/positronium.htm

Every Fundamental Particle Has It’s Anti-particle With the Same Mass but Opposite Charge and Magnetic Moment



We Work With Positrons (E+) the Antiparticle of Electrons (E-)
Electrons are accelerated by a LINAC towards target and deflected by nucleus to make Gamma rays
Gamma Rays(.511 Mev photons) Produce Pairs of Electrons and Positrons

Energy Mass Relationship

$$E = mc^2$$

$m_{e+} = 9.109 \times 10^{-31}$ Kg
$c = 3 \times 10^8$ m/s

$1\ \mu g \sim 10^{21}\ e^+$

Source	Energy Density (j/Kg)
TNT	4.7×10^6
Fission (U_{235})	8.2×10^{13}
Antimatter	18.0×10^{16}

Specific Energy Antimatter = 180Mj / μg
1 μg e^+ = 37.8 Kg TNT

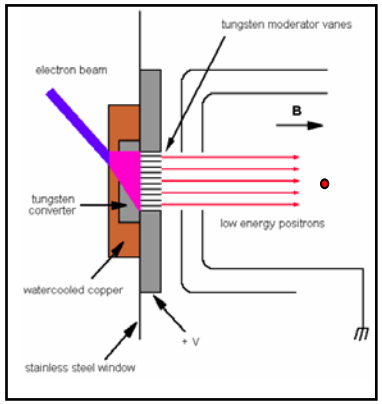
Basic Benefits of Positrons

- Largest Energy Density Known (180 Megajoules per microgram)
- Long History of Research (1932-2001)
- Stored in Charged Mode Using Electro Magnetic Devices
- Emit Modest Energy (511kev) Gamma Rays Which Deposit Energy Locally
- No Radioactive Nuclear Residue From Annihilation of Positrons
- Can Be Produced in Sufficient Quantities for Proof Of Concept Experiments

Basic Technology:

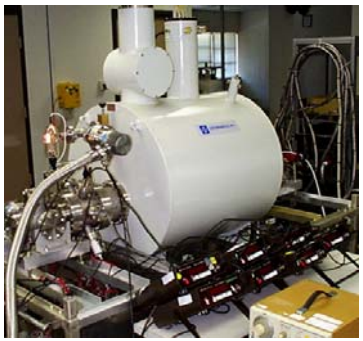
Produce Positrons with Wash State DeuteronAccelerator or Argonne Linac

100 Mev Electrons



Tungsten Target

Tungsten or Hydrogen Moderator Slows Positrons

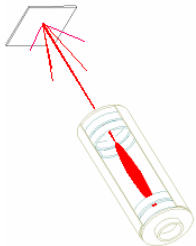


Positron Trap Confines Positrons

Positrons Are Electromagnetically Turned

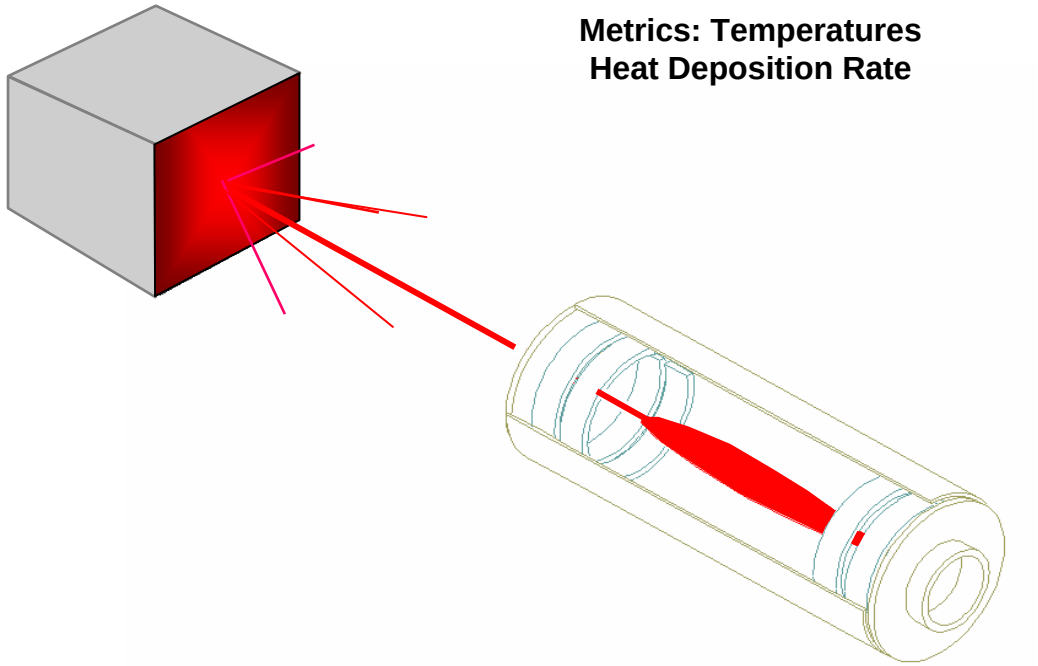
Bench Test Experiments

Metal Target Heat vs Time Profile



Basic Technology:

Heat vs Time Profile

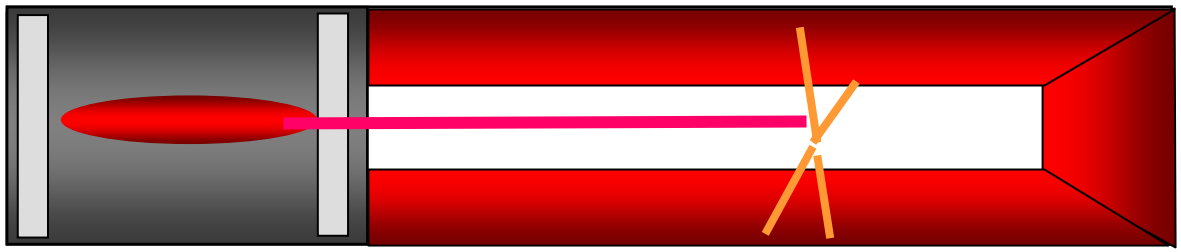


Basic Technology
PEC Annihilation Chamber

Positron Beam

Gamma Rays Impact And Heat Walls

Positron Trapping Device

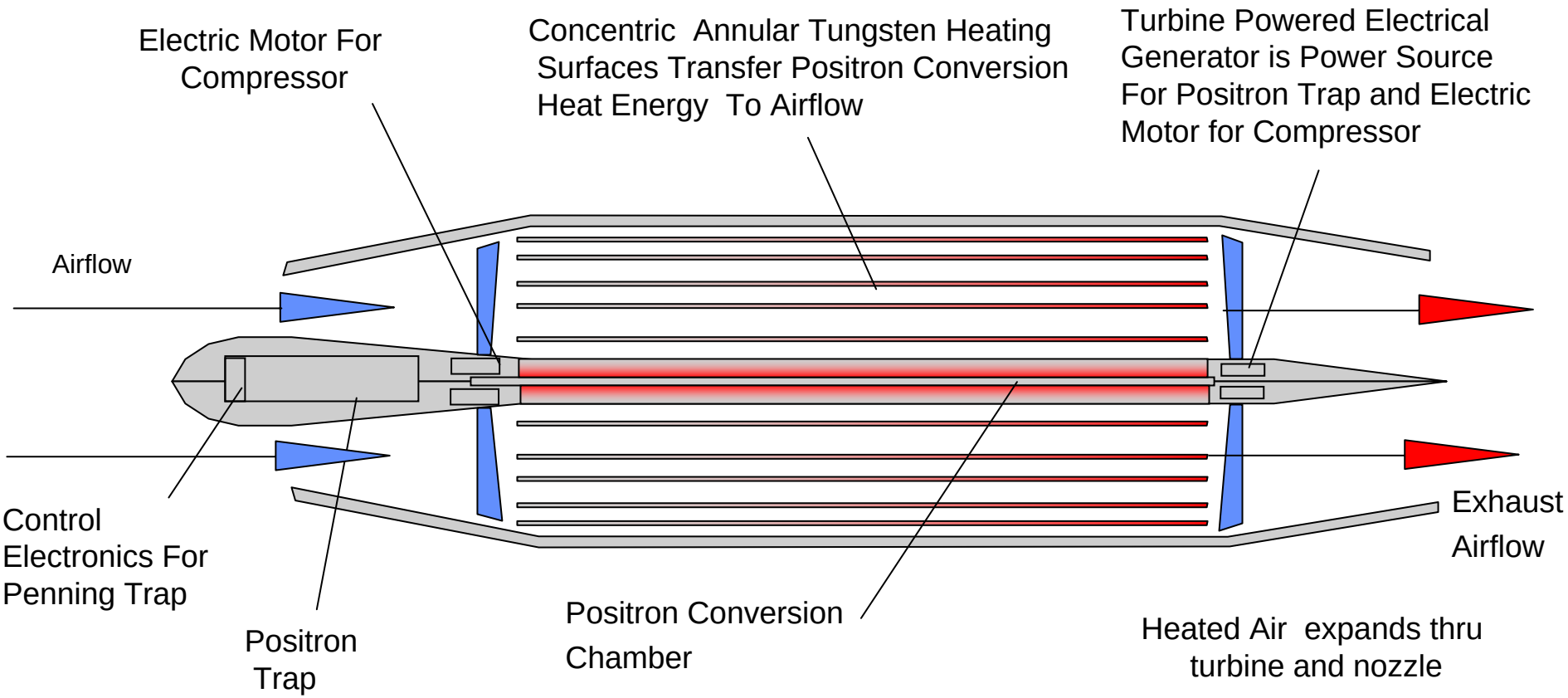


Positrons Annihilate With Free Electrons Producing Two Soft 0.51 Mev Gamma Rays

Tungsten Annihilation Chamber

Positron Energy Conversion Leaves No Nuclear Residue!

Basic Technology
Conceptual Turbo Ramjet Rocket



- Compressor and turbine can be feathered to convert turbo jet to ramjet
- Exo-atmospheric Capability Achieved by including Onboard Working fluid Tanks

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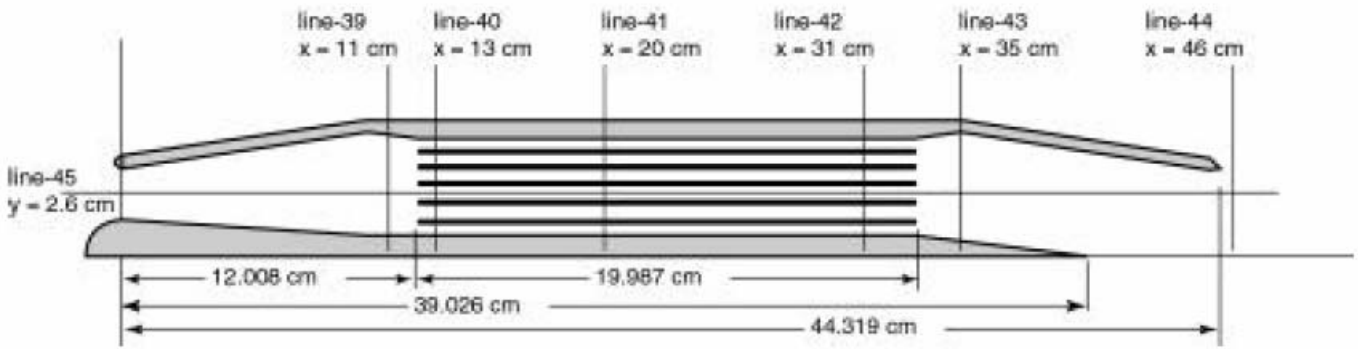
Ramjet Simulations

STI CFD Research (USAF)

- USAF contract to investigate positron heating in ramjets.
- Configuration below used for preliminary case of M = 0.5 - 1.3.
- Geometry used in FLUENT CFD code.



Demonstrated Technology

Nuclear Reactor Heated Ramjet

Vought *SLAM* (*Pluto*)

In the mid-1950s, nuclear ramjet powerplants for cruise missiles were studied, and in January 1957 the development of such a weapon system was officially initiated as Project *Pluto*. The reactor for the ramjet was developed at the Lawrence Radiation Laboratory (which eventually became the Lawrence Livermore National Laboratory, LLNL), while ramjet itself would be built by Marquardt.

The initial reactor prototype was called TORY-IIA and ran for the first time in May 1961. TORY-IIA was a proof-of-concept powerplant not intended for an actual flight-rated ramjet, and was followed by the larger and more powerful TORY-IIC. The latter was run-up on the ground to full power on 20 May 1964. The TORY-IIC consisted of 465000 tightly packed small fuel rods of hexagonal section, with about 27000 air-flow channels between them to heat the incoming high-pressure airflow. For the ground tests, the airflow was provided by a huge reservoir of compressed air, and TORY-IIC produced a thrust of about 170 kN (38000 lb) at a simulated airspeed of Mach 2.8. TORY-IIC was intended for use in the first flight tests, but operational missiles would probably have used a further improved design called TORY-III. The latter was however still in the design phase when the whole program was cancelled.

While reactor development was going on, the USAF had selected an airframe contractor for the actual cruise missile. The latter was known as *SLAM* (Supersonic Low-Altitude Missile), but the project name *Pluto* was sometimes also used when referring to the missile. In 1963, Ling-Temco-Vought (LTV) was awarded the *SLAM* development contract.

SLAM was a wingless design optimized for Mach 3+ flight at 300 m (1000 ft) altitude. It featured a ventral air intake for the ramjet, three fixed stabilizing fins at the rear, and three small all-moving control fins near the tip. *SLAM* was to be launched by multiple solid-fueled rocket boosters, which would propel the missile to ramjet ignition speed. Several basing options (including air-launch) were considered for *SLAM* but most likely it would have been launched from some sort of hardened shelters on the ground. Flying at Mach 3+ at very low level, the missile would have to withstand very severe aerodynamic and thermal stresses, and it was therefore designed with a very sturdy structure (yielding the nickname of "Flying Crowbar").

Flying and Terrestrial Nuclear Reactors

Flying and Terrestrial

Nuclear Reactors

In 1955, the Laboratory and Los Alamos began work on Rover, a project intended to supply nuclear propulsion for space travel. The nuclear rocket program continued

for many years at Los Alamos with many technical successes, while Livermore's attention shifted in 1957 a new flying reactor effort, Project Pluto, for the Atomic

Energy Commission and the Air Force. An awesome undertaking, Project Pluto entailed the design and testing of a nuclear ramjet engine for low-flying, supersonic

cruise missiles that could stay aloft for many hours. For Project Pluto, Livermore designed and built two Tory II-A test reactors to demonstrate feasibility,

and Tory II-C was designed as a flight-engine prototype. Laboratory experts in chemistry and materials science were challenged to devise ceramic fuel elements that

had the required neutronics properties for the reactor yet were structurally strong and resistant to moisture and oxidation at high temperatures. Because the reactors

needed hundreds of thousands of the elements, they also had to be mass producible. Testing the reactors required novel remote-handling technologies, as well as systems

capable of ramming about a ton of heated air through the reactor each second. For 45 seconds on May 14, 1961, Livermore tested the Tory II-A at the

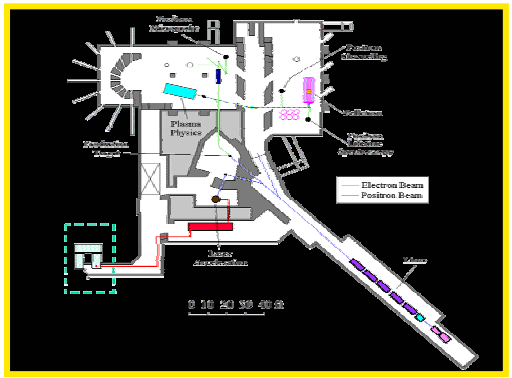
Nevada Test Site. After additional successful experiments in 1961, Tory IIC was designed and built. Generating 500 megawatts of power (about half the power capacity of Hoover Dam), it was successfully tested in the spring of

1964. All six tests of the two Tory reactors were conducted without failure. However, that summer, the project was

halted for lack of a firm military commitment.

Positron Enabling Technology

Positron Sources

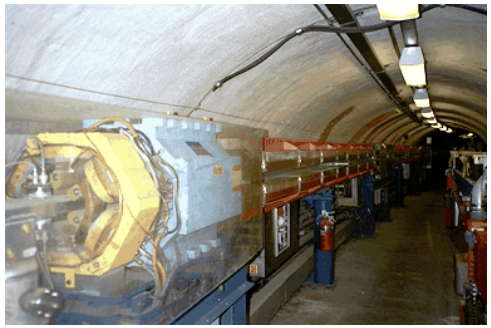


LINAC

Courtesy LLNL

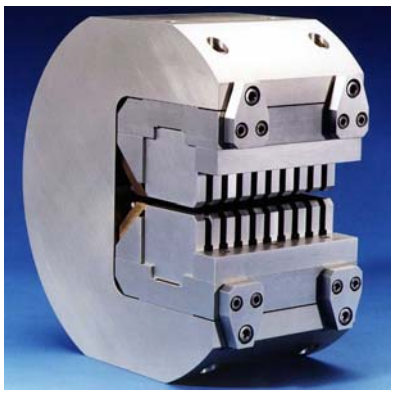
Deuteron Accelerator

Courtesy ACCSYS



CESR Storage Ring

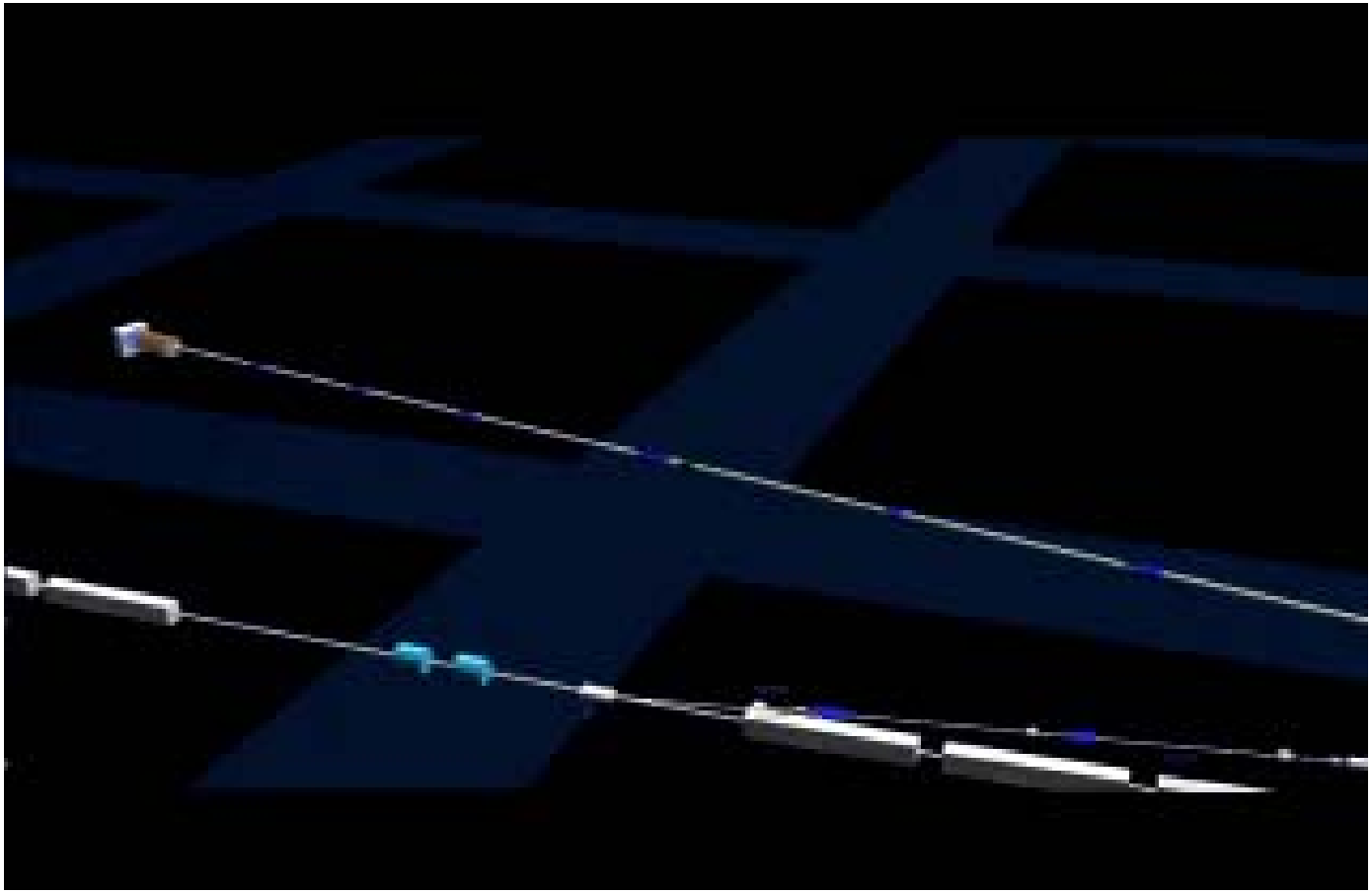
http://www.lns.cornell.edu/public/lab-info/ring.html



SLAC Undulator

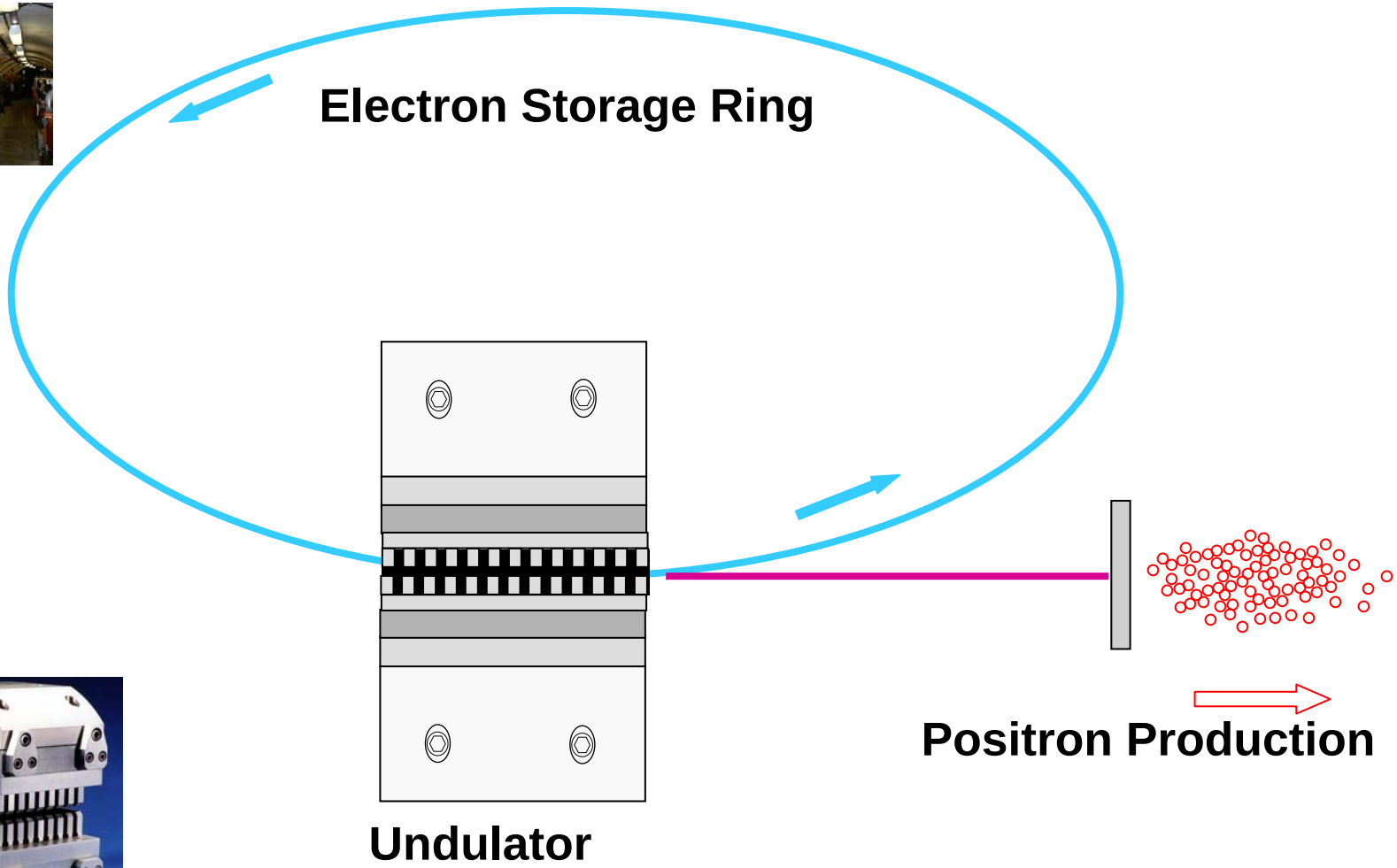
http://www-ssrl.slac.stanford.edu/lcls/images/undu2.jpg

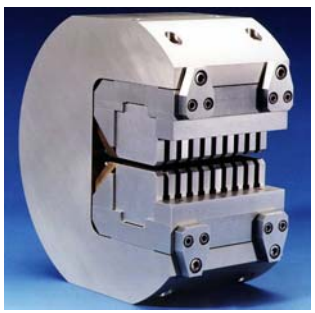
Positron Production Cartoon



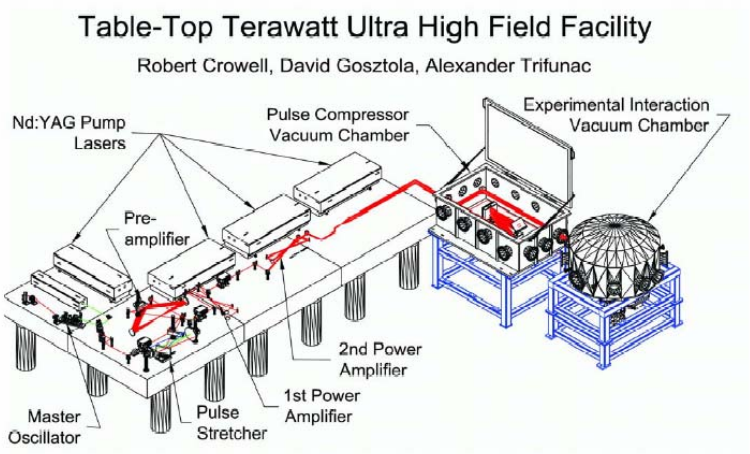
Return

Taken From http://www.lns.Cornell.edu/public/lab-info/linac.html


Electron Storage Ring
Undulator
Positron Production



Femto-second Laser Positron Production



Presto! Light Creates Matter

As nuclear bombs and many physics experiments show, turning matter into light, heat, and other forms of energy is nothing new. Now a team of physicists has demonstrated the inverse process--turning light into matter. In the 1 September *Physical Review Letters*, the team describes how they collided large crowds of photons together so violently that the interactions spawned particles of matter and antimatter: electrons and positrons (antielectrons). Physicists have long known that this kind of conjuring act is possible, but they have never observed it directly.

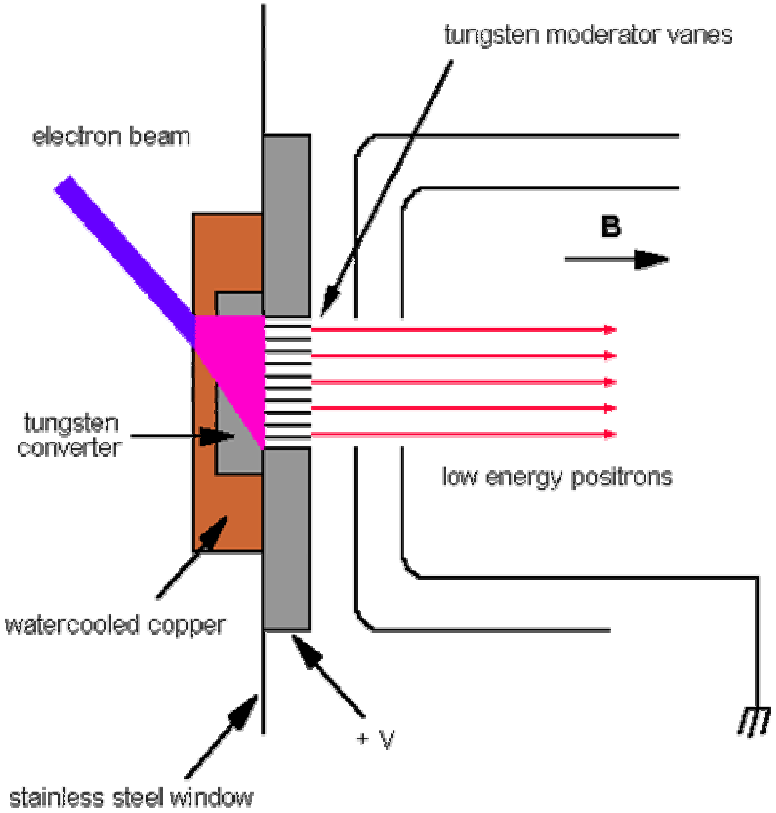
Working at the Stanford Linear Accelerator Center (SLAC), the 20-physicist collaboration focused an extremely intense laser beam at a beam of high-energy electrons. When the laser photons collided head-on with the electrons, they got a huge energy boost, much like ping-pong balls hitting a speeding Mack truck, changing them from visible light to very high-energy gamma rays. These high-energy photons then rebounded into the path of incoming laser photons, interacting with them to produce positron-electron pairs.

http://www.hep.princeton.edu/~mcdonald/e144/sciencenow820.html

http://chemistry.anl.gov/Research%20Highlights/Gostzola-TTTUHFF-Highlight.pdf

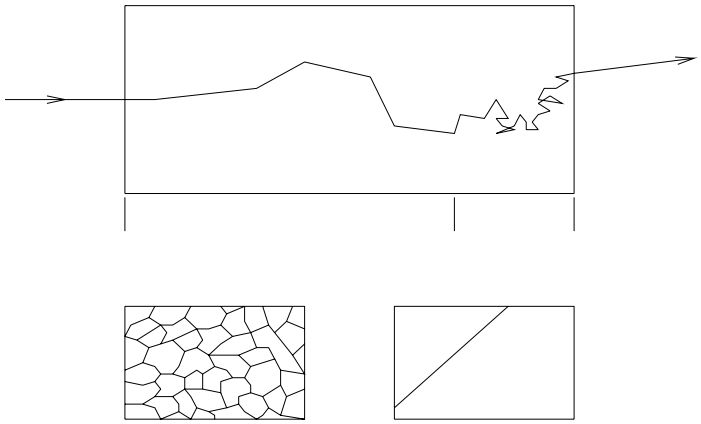
Tera-watt lasers can be used to produce Positrons

Positron Moderation



Tungsten Moderator

Courtesy Dr Wolfgang Stoeffl, LLNL



[E.M. Gullikson and A.P. Mills, Jr., Phys. Rev. Lett. **57**, 376 (1986)]

Solid Hydrogen Moderator

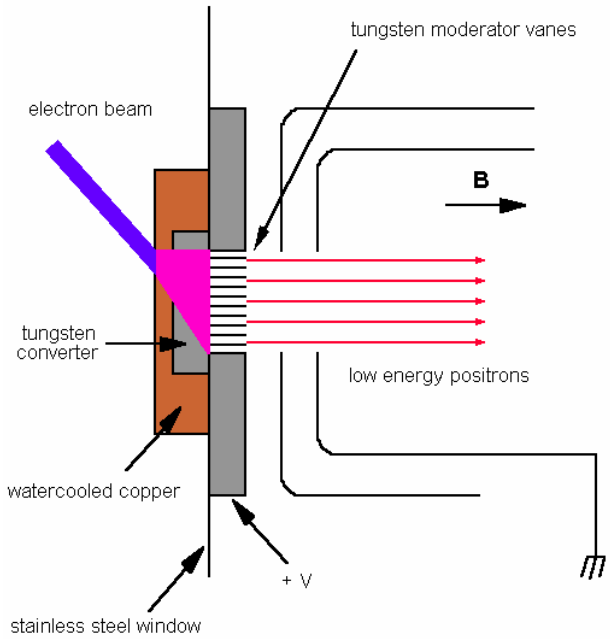
Courtesy Dr Mario Fajardo, AFRL

Positron Moderation Approaches

Positron Moderation Approaches

Tungsten Moderator -

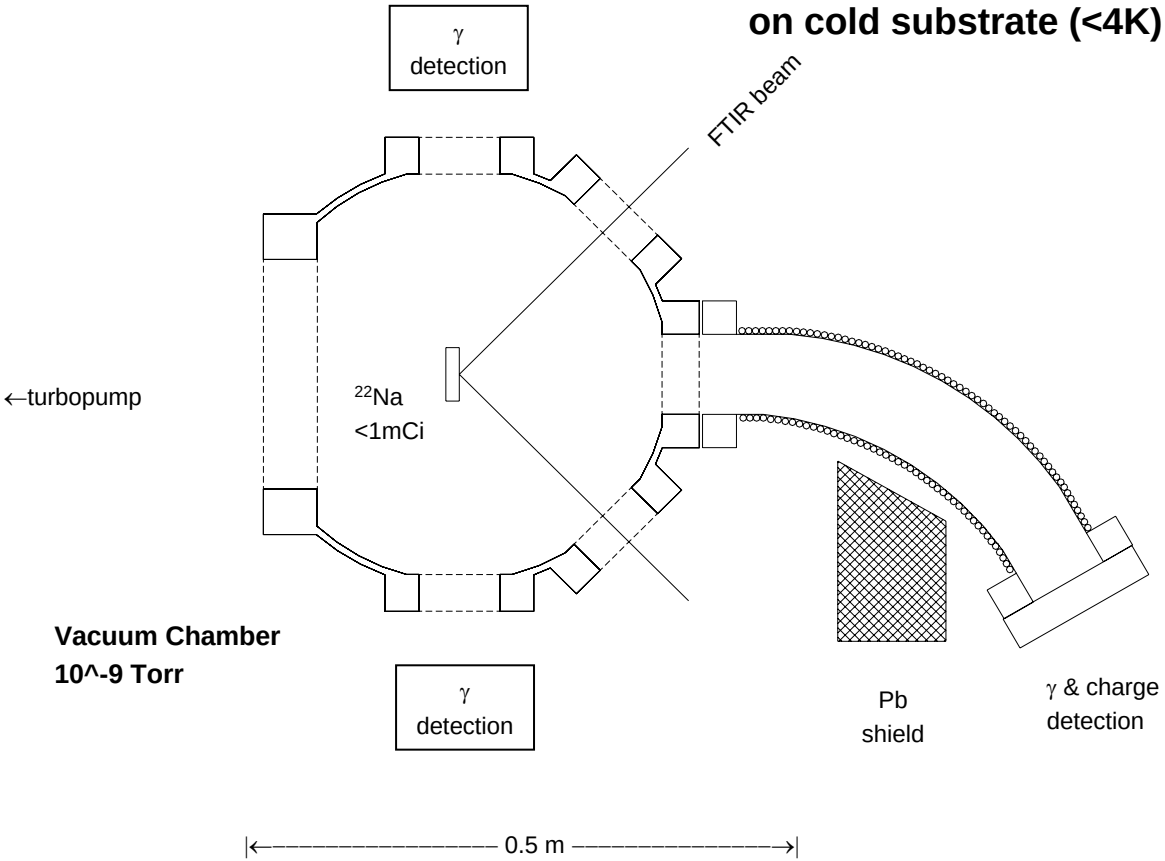
Efficiency = 10^-5

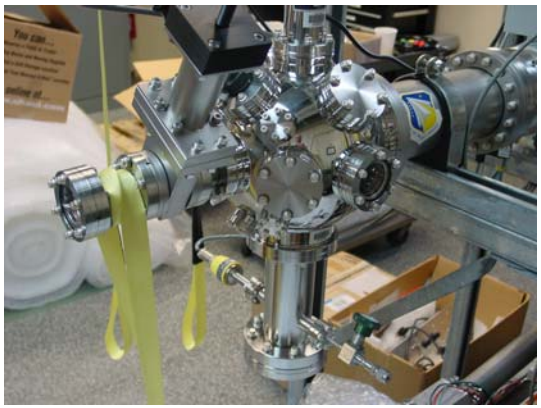


AFRL/MNME Moderation Experiment

Solid Hydrogen Moderation
Efficiency = 10-3

Solid Hydrogen Deposited
From Above)
on cold substrate (<4K)



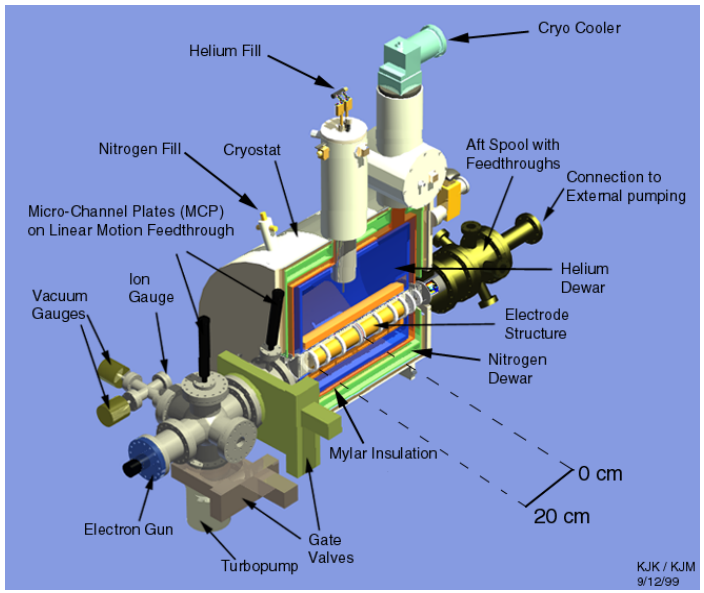


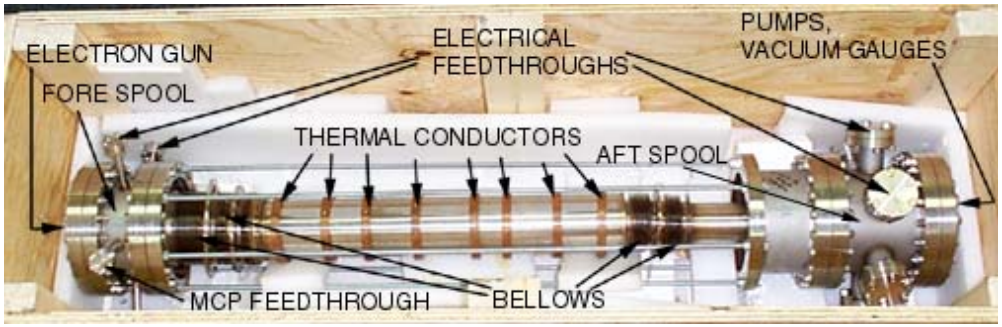
Potential to increase positron moderation efficiency by a factor of 2 to 10

IR Spectroscope used to Investigate Hydrogen crystal Quality

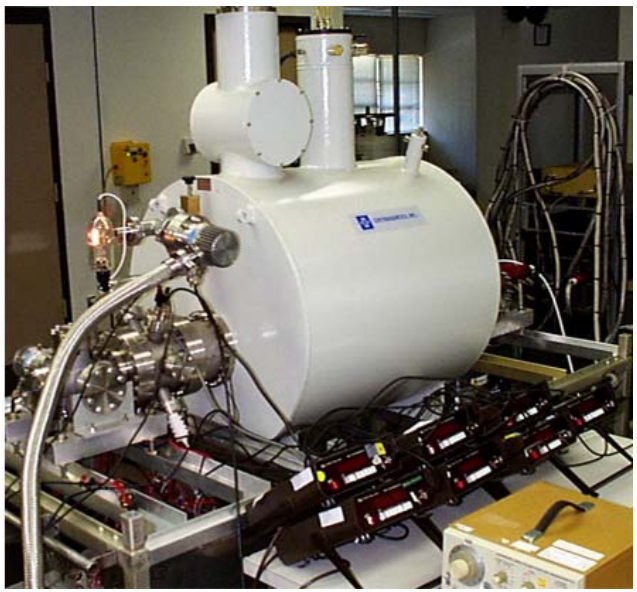
Positron Confinement Approaches

Positron Confinement
Current NASA Penning Trap





Marshall Space Flight Center
High Performance Antimatter Trap (HiPAT)
Traps 10^{12} e+ at 25KV



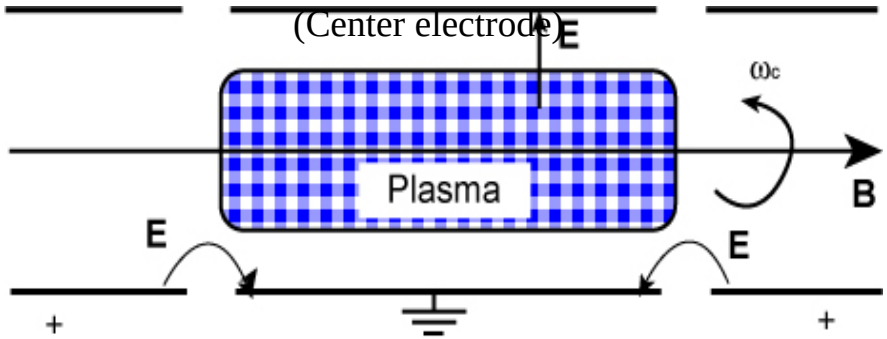
Designed and Developed by Dr G Smith, Positronics Research LLC.

POSITRONICS RESEARCH, LLC

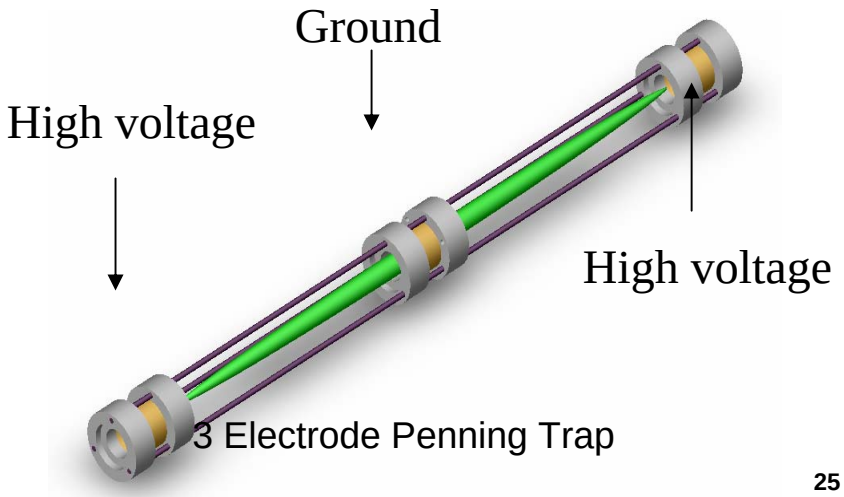
Technical Discussion

How does a Penning Trap Work?

- **Cylindrical geometry.**
- **Inject positrons or test electrons along axis of symmetry.**
- **Apply magnetic field in axial direction so positrons (e+) are tightly wound around field lines and do not diffuse radially.**
- **Apply large electric potential in a 3-electrode configuration to provide axial confinement.**

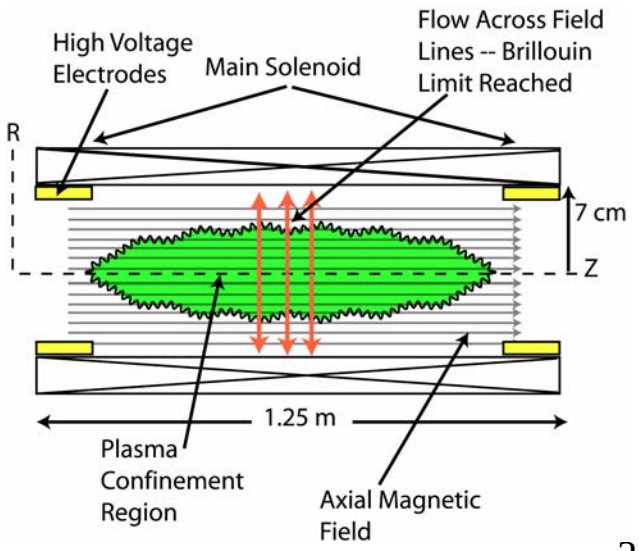


Basic Penning Trap Layout



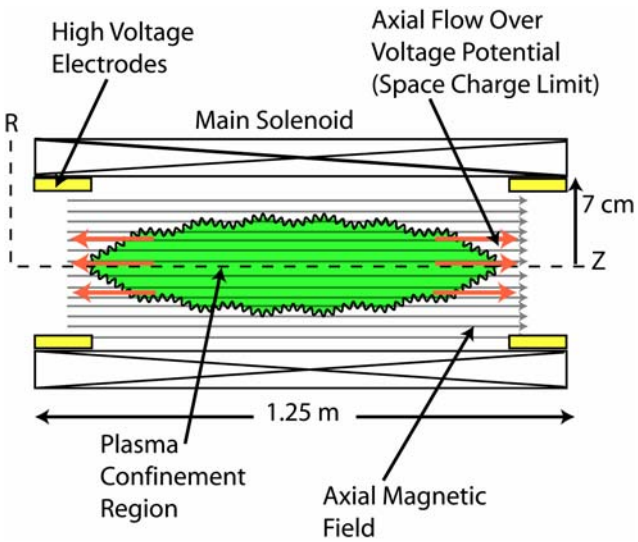
3 Electrode Penning Trap

What Are Limitations for Penning Traps?



Brillouin Limit $$n_b = \frac{B^2}{8\pi mc^2}$$

n_b = number density (#/cm^{-3})
B = axial magnetic field strength (Tesla)
m = particle mass (kg)
c = speed of light



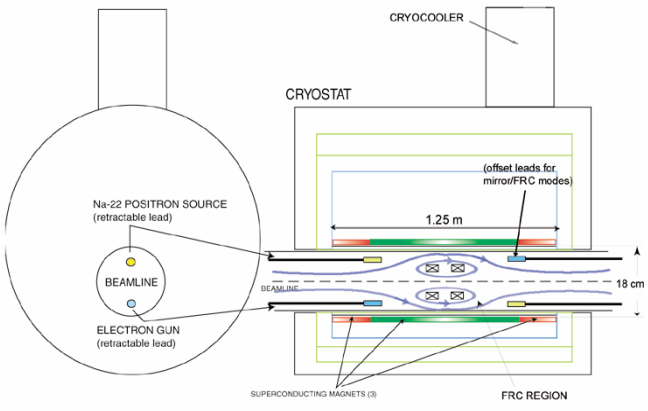
Space Charge Limit

$$V_s \cong 1.4\times10^{-7}\frac{N_b}{L}\left[1+2\log_e\left(\frac{R_w}{R_p}\right)\right]$$

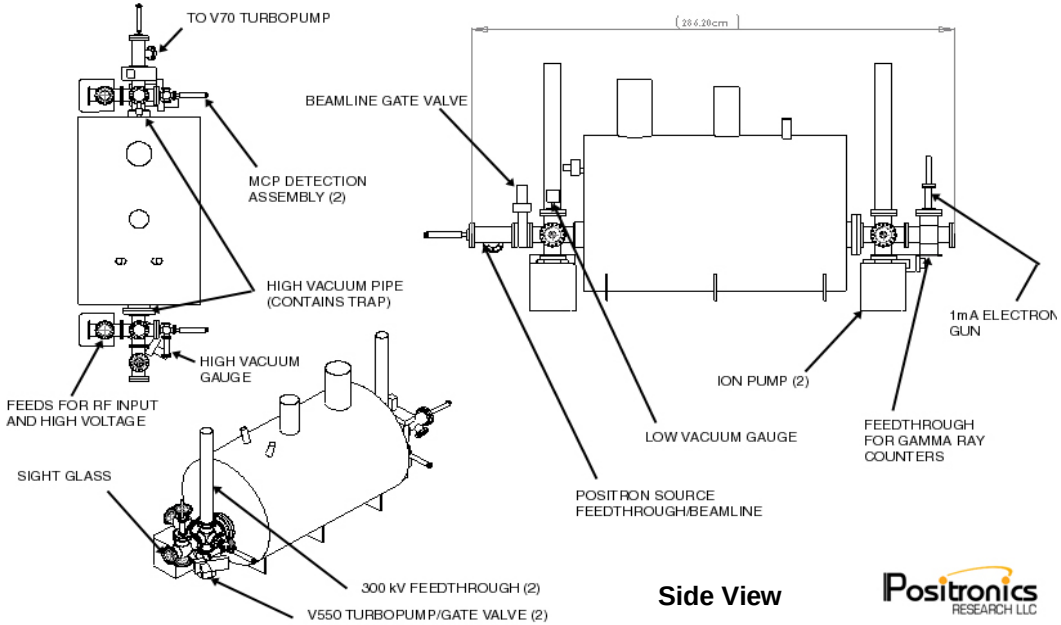
N_b = total number
L = Length of plasma (cm)
R_w = Wall radius
R_p = Plasma radius
V_s = Space charge Potential

Three in One Confinement Device

This Device Will Act as Penning Trap When Green Solenoid Magnet Is Activated and a Magnetic Mirror When Green Solenoid and Red Pinch Coils Are Activated and as FRC Device When Solenoid, Pinch and Field Reverse Coils are Activated



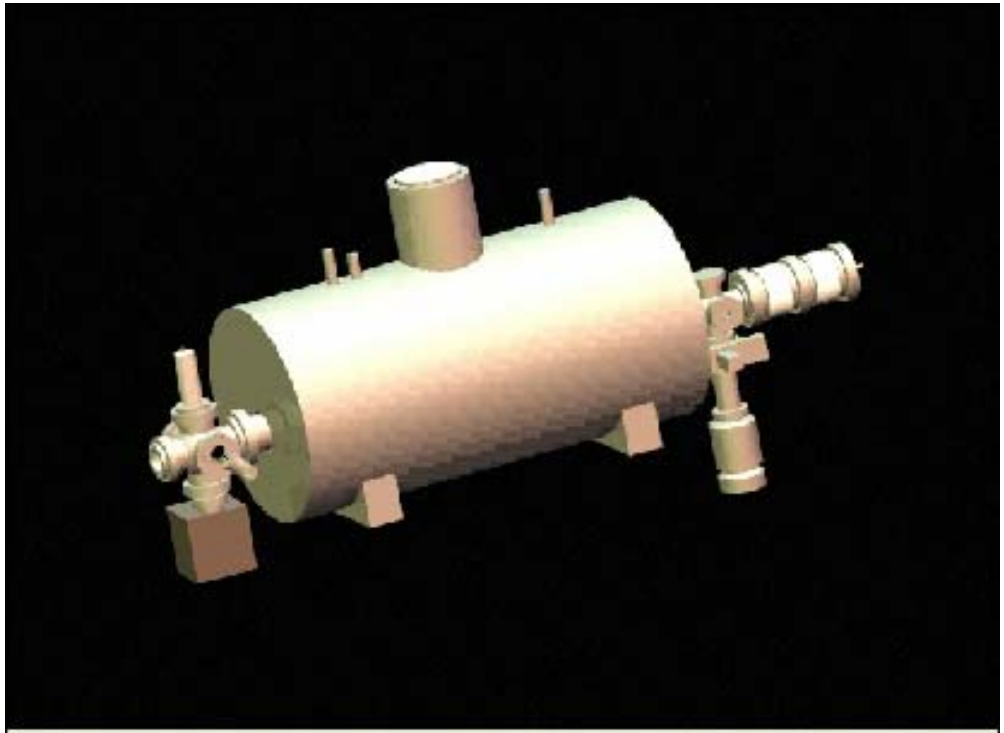
Cross Section



Side View

Courtesy Dr Gerry Smith, PRLLC

CRYOSTAT ANNIMATION



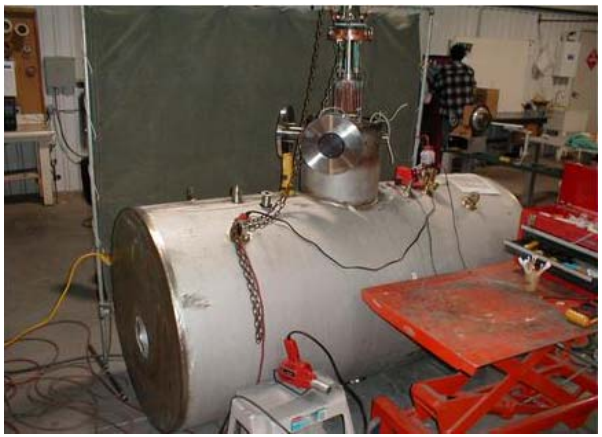
full cryostat assembly rev_plas3

Three In One Device In Fabrication

Cryomagnet in Final Tests

at Cryomagnetics, Oak Ridge, TN

December, 2003

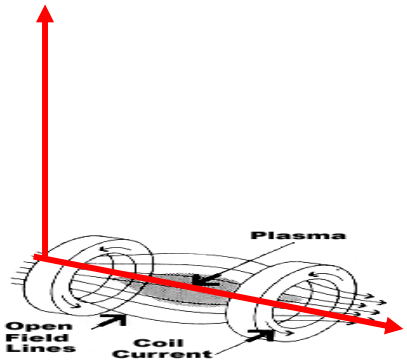


Insert Assembly

Electrode Assembly

Magnetic Mirror Simulation

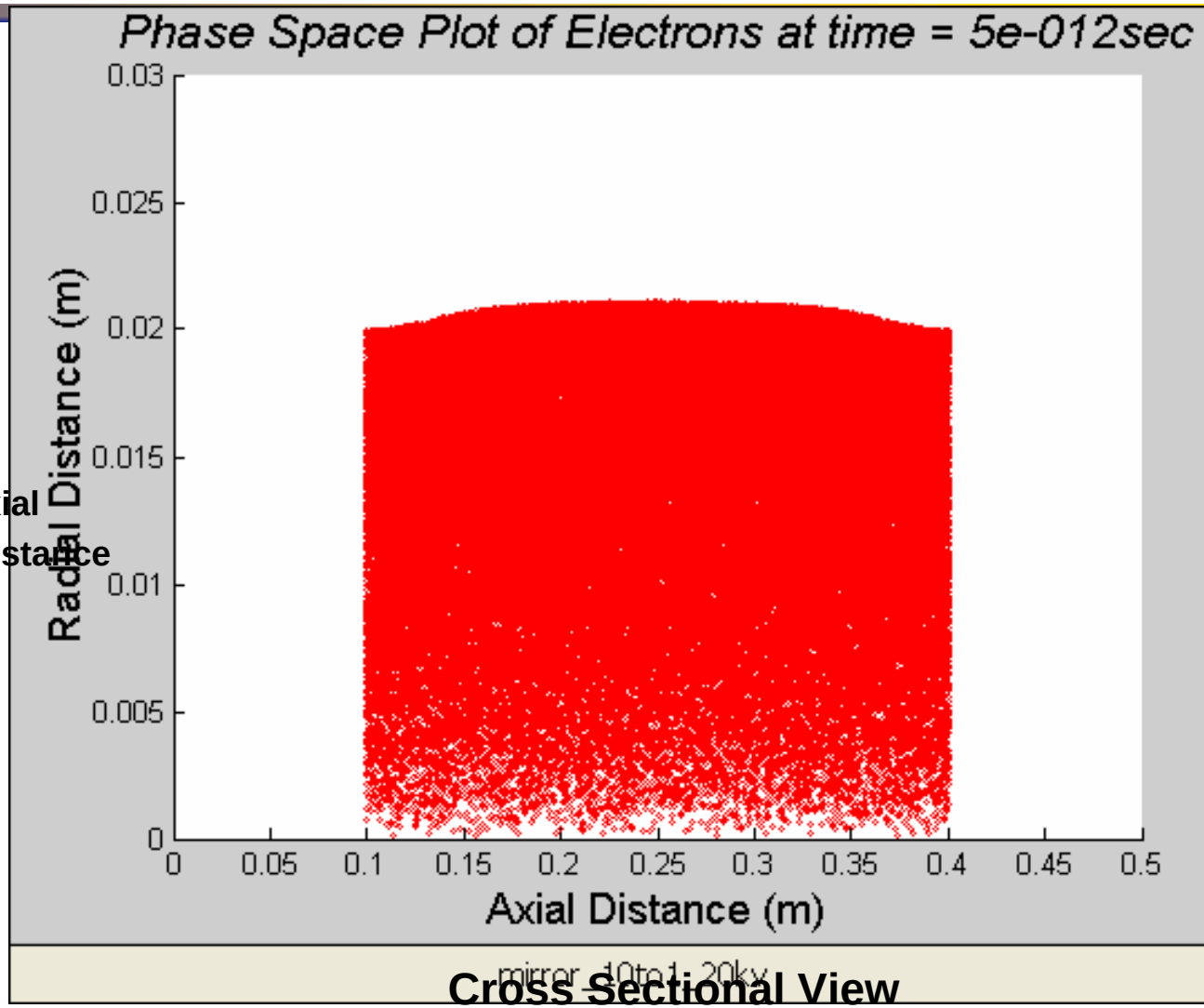
Radial Distance



Axial Distance

http://library.thinkquest.org/17940/texts/magnetic_confinement/magnetic_confinement.html

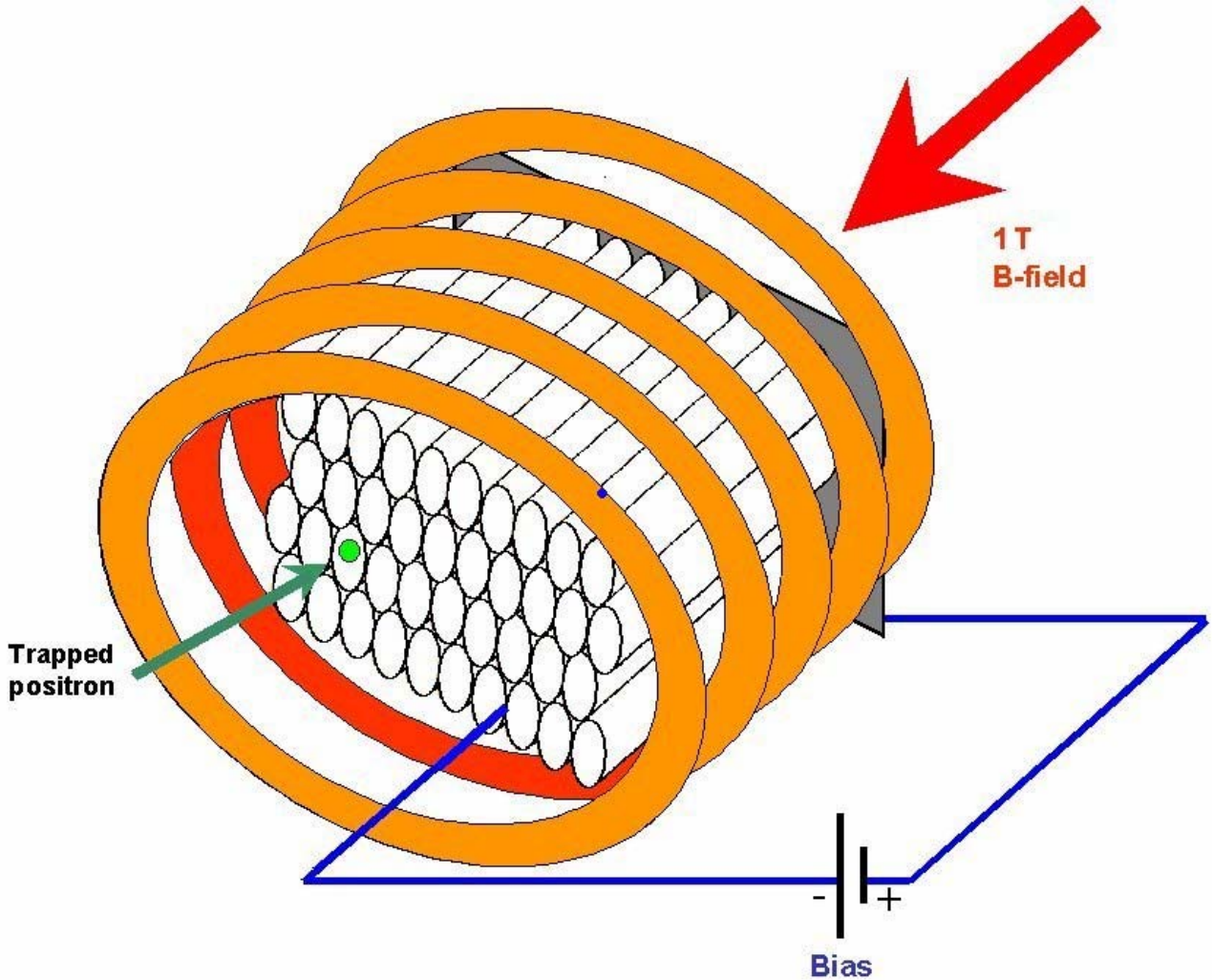
Magnetic Mirror



Cross Sectional View

Courtesy Dr Gerry Smith, PRLLC

Micro Tubule Confinement of Positrons



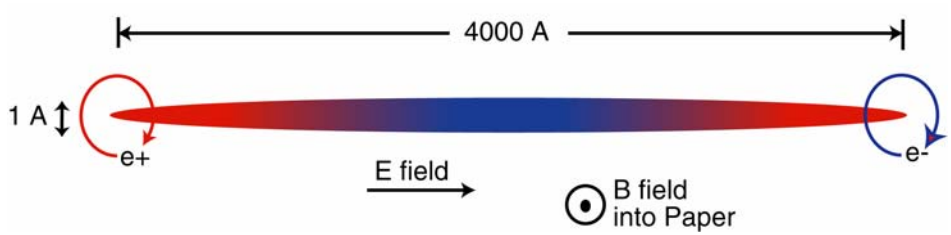
Taken From Positron Confinement Proposal By

Dr Kelvin Lynn, Wash State Univ, with Permission

Stabilization and Confinement of Atomic Positronium

Long Lived States of Positronium

- **Recent theory suggests Ps can be stabilized in crossed electric and magnetic fields.**
- **In these fields the electron and positron are "pinned" by the magnetic field while the electric field stretches the atom apart.**
- **The resulting potential barrier that must be tunneled to annihilate is extremely large.**
- **Quantum chemistry calculations identify coulumbic quantum states with potential lifetimes of 1 year or longer.**



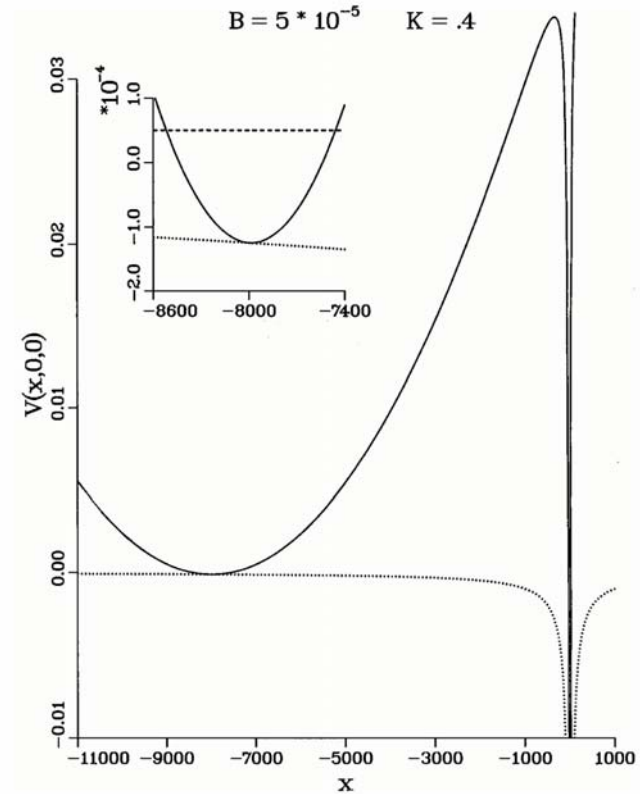


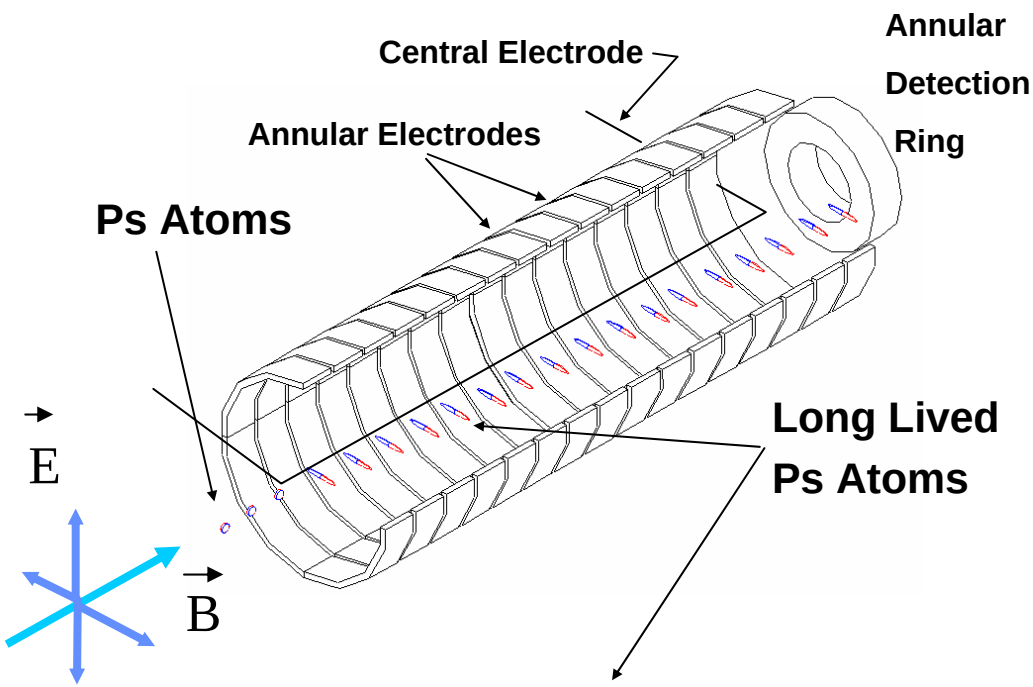
FIG. 1. Potential $V(x, y = 0, z = 0)$ of the internal motion of positronium at $B = 5 \times 10^{-5}$ and $K = 0.4$ (solid line). Also shown is the field free Coulomb potential for zero pseudomomentum (dotted line). The inset is an amplification of the outer well in the region of the minimum showing the ionization energy (dashed line).

J. Ackermann, et al, Phys. Rev. Lett. 78, 199, 1997.

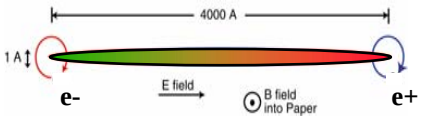
Experiment to Demonstrate Positronium Stabilization and Confinement

Stabilization

1. Positronium is made by impacting a beam of positrons on a tungsten target which generates a positronium beam

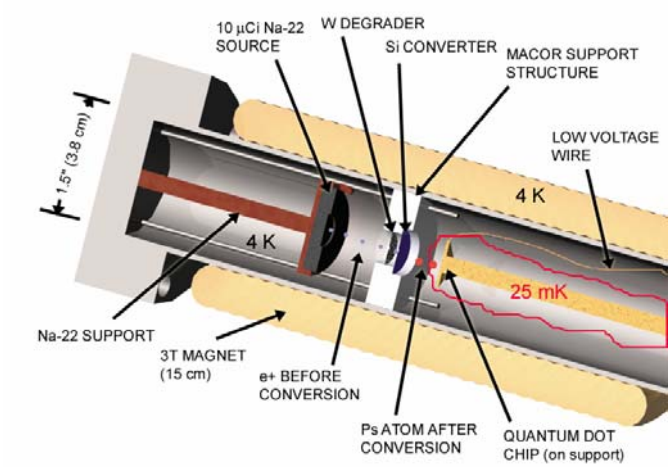


Crossed Electric and Magnetic Fields



2. Positronium atoms (Ps) are made long lived by crossed electric and magnetic fields.

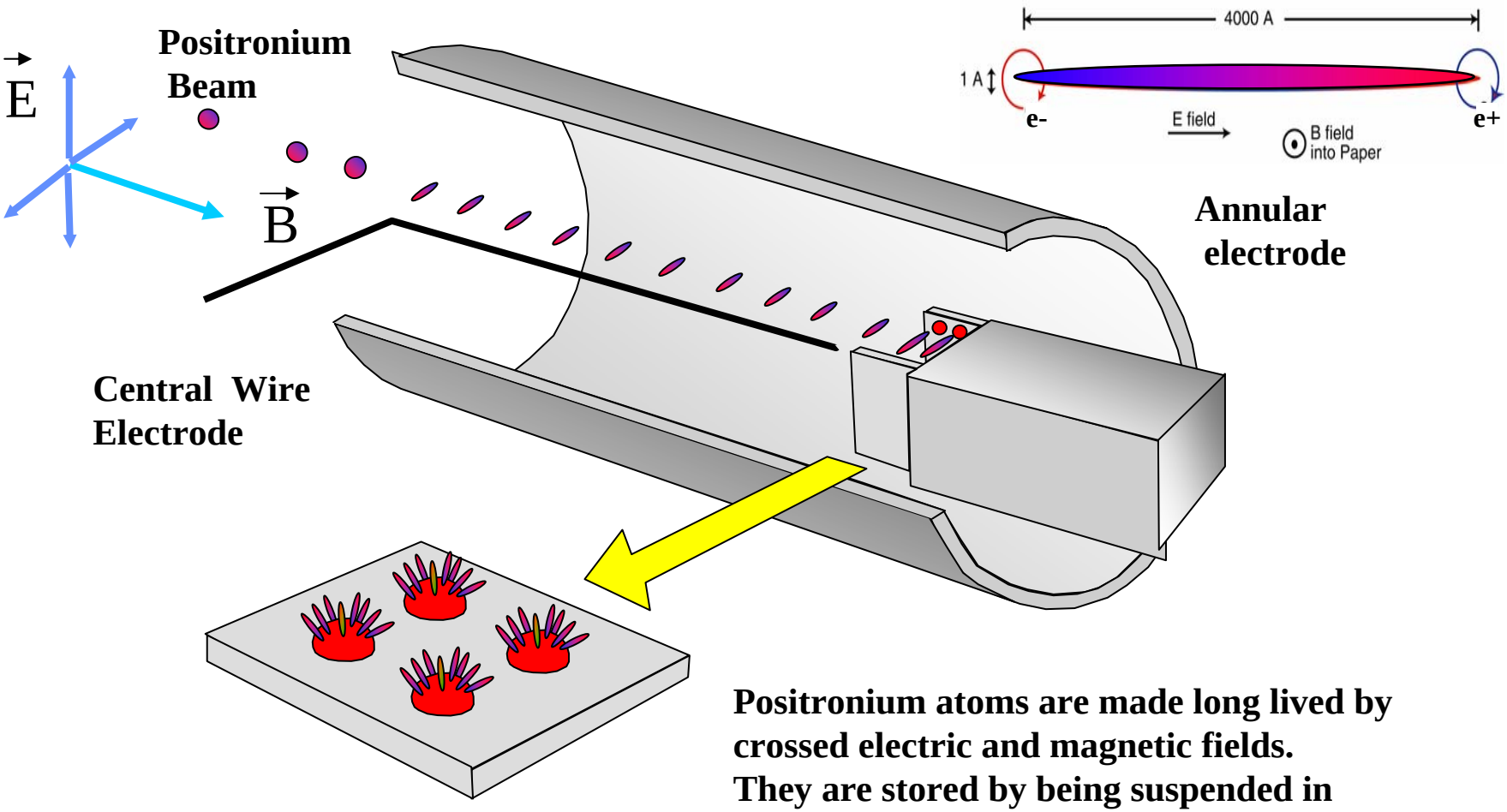
- Stabilized Ps atoms are directed and stored on a 1cm x 1cm quantum dot nanochip.
- Approximately 10^{11} Ps atoms may be stored per chip



Confinement

POSITRONICS RESEARCH, LLC

Quantum Dot Storage of Positronium



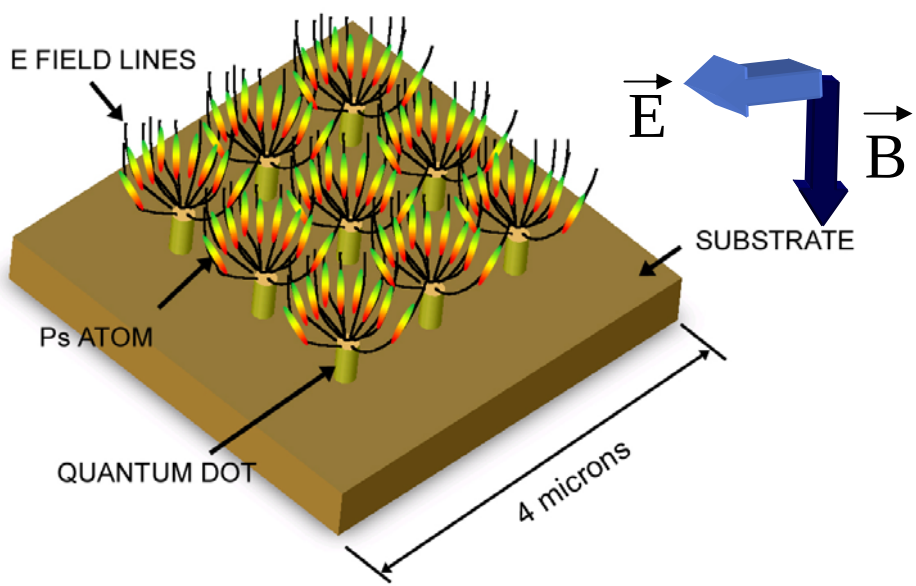
Positronium atoms are made long lived by crossed electric and magnetic fields. They are stored by being suspended in potential wells around quantum dots

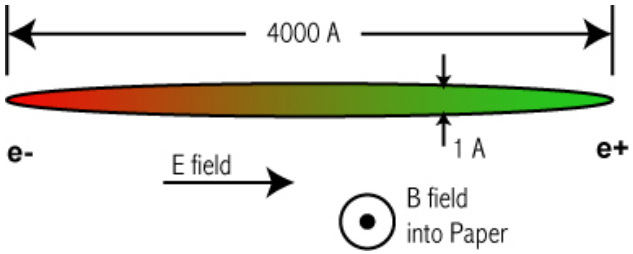
Concept Courtesy of Positronic Research LLC

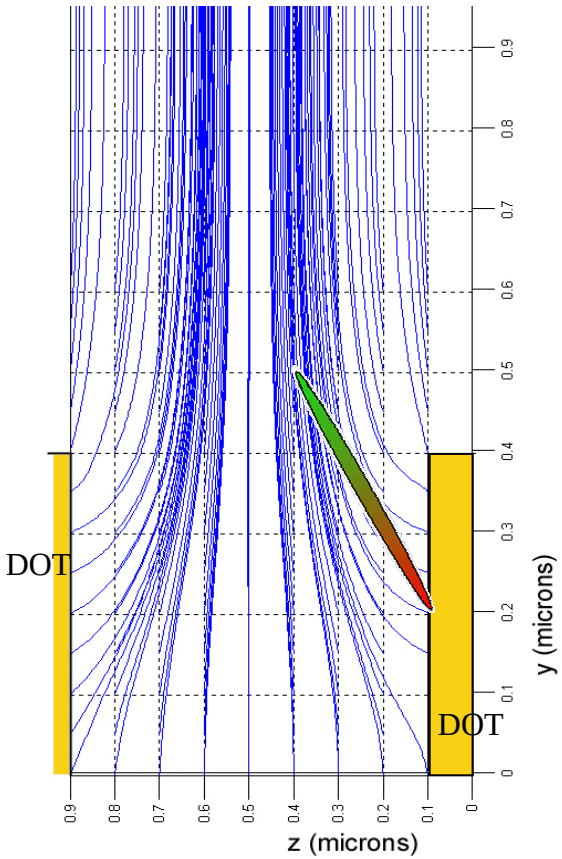
Closer Look at the Quantum Dots

--Ps atoms, stabilized by crossed electric and magnetic fields, follow electric field streamlines and fall into the potential wells around the quantum dots.

--Approximately 1000 Ps atoms can be trapped per quantum dot.



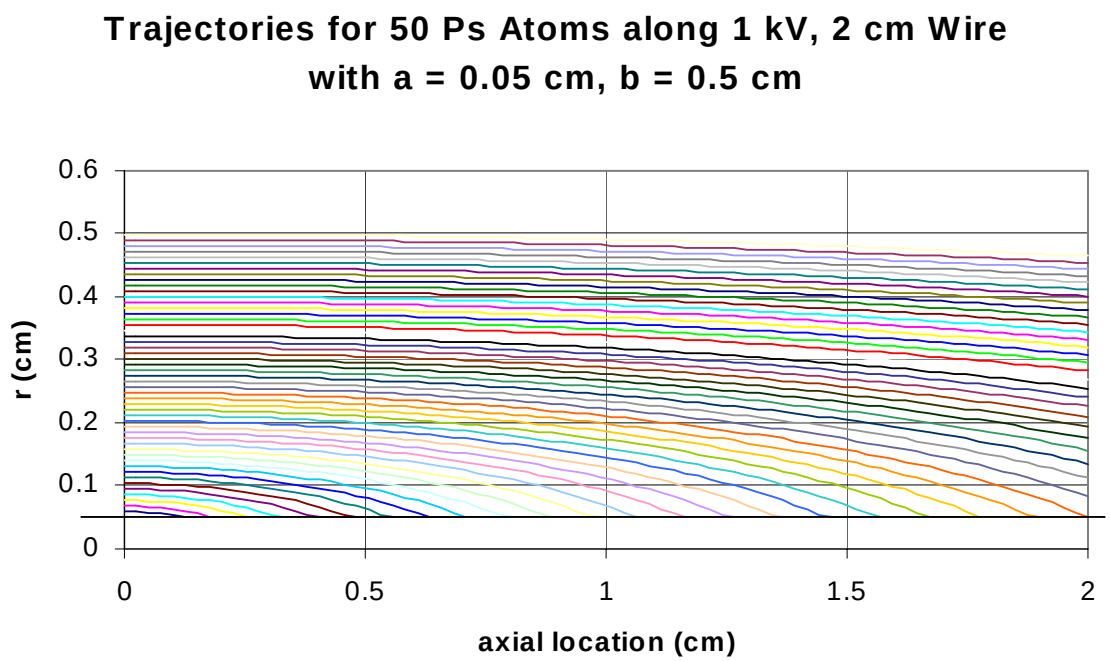




Trajectory Analysis Shows Ps Atoms Impacting Wire

- **Given an initial radius r_0, find new radius r of 1 eV Ps atom at increased time steps.**
- **Transcendental Eqn:**

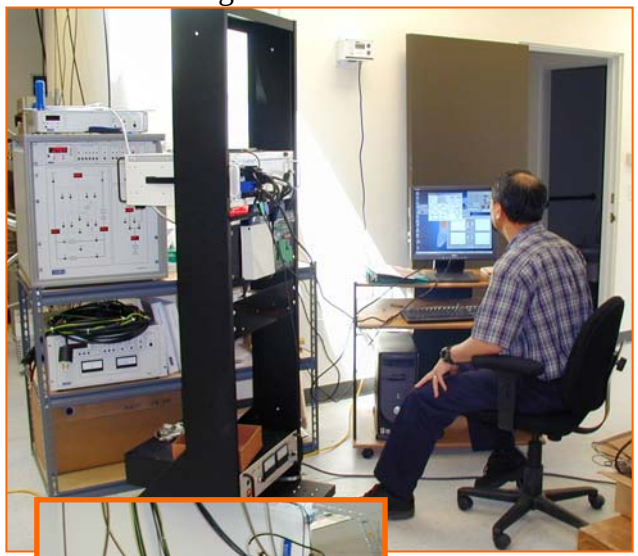
$$= t\sqrt{kc_2} = \sqrt{rr_0^2 - r^2 r_0} + \frac{r_0^{3/2}}{2}\left[\frac{\pi}{2} - \sin^{-1}\left(\frac{2r - r_0}{r_0}\right)\right], a < r < r_0$$



Installation Checks Were Excellent
Base Temperature of 10 mK Reached

Insertion into OVC (4He Dewar)

LABView Integration

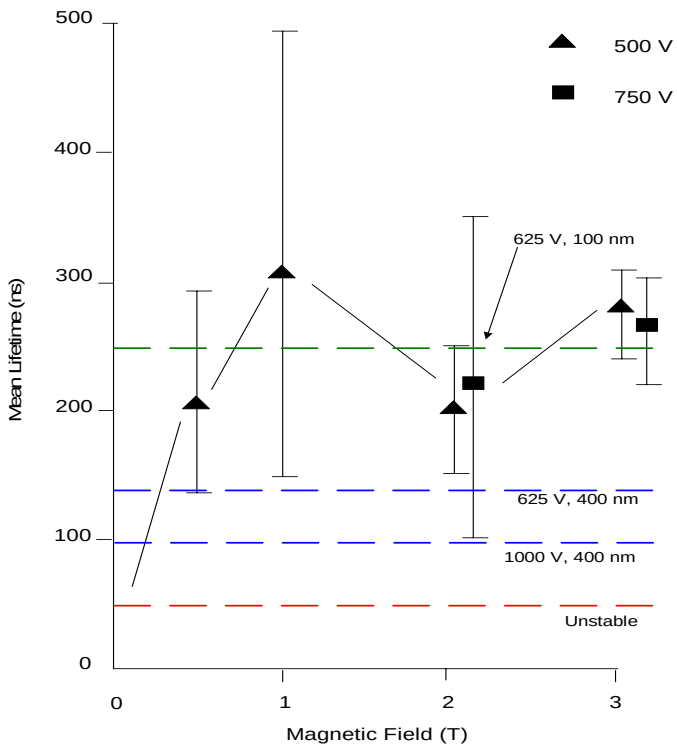


Leak Detection Before and After Nitrogen Precooling (below)

Fully Operational Mode (with 4He)

Magnet integrity checks, base temperature verification

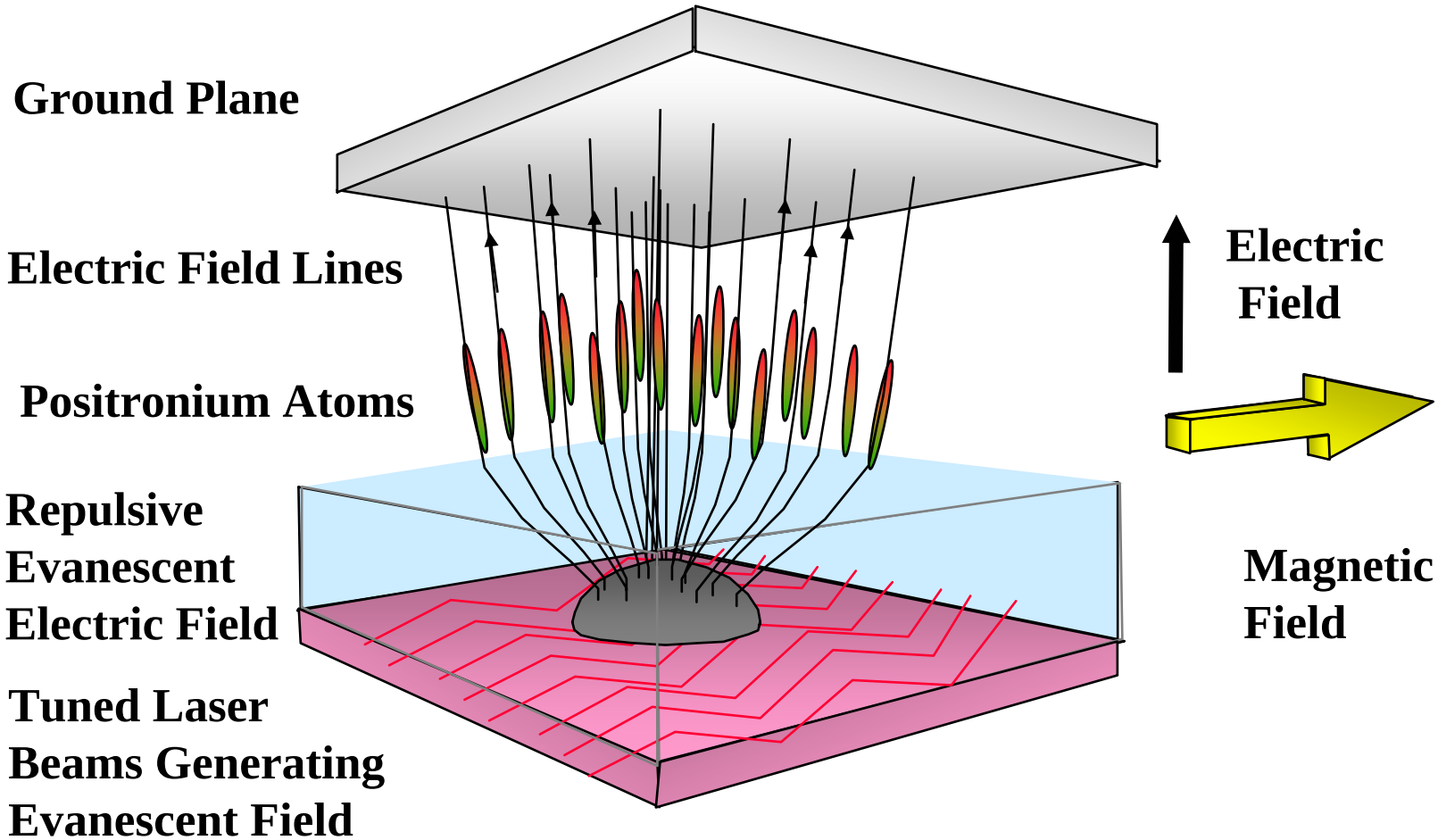
Lifetimes Versus Magnetic and Electric Field Long Lifetime Fits



Preliminary Conclusions

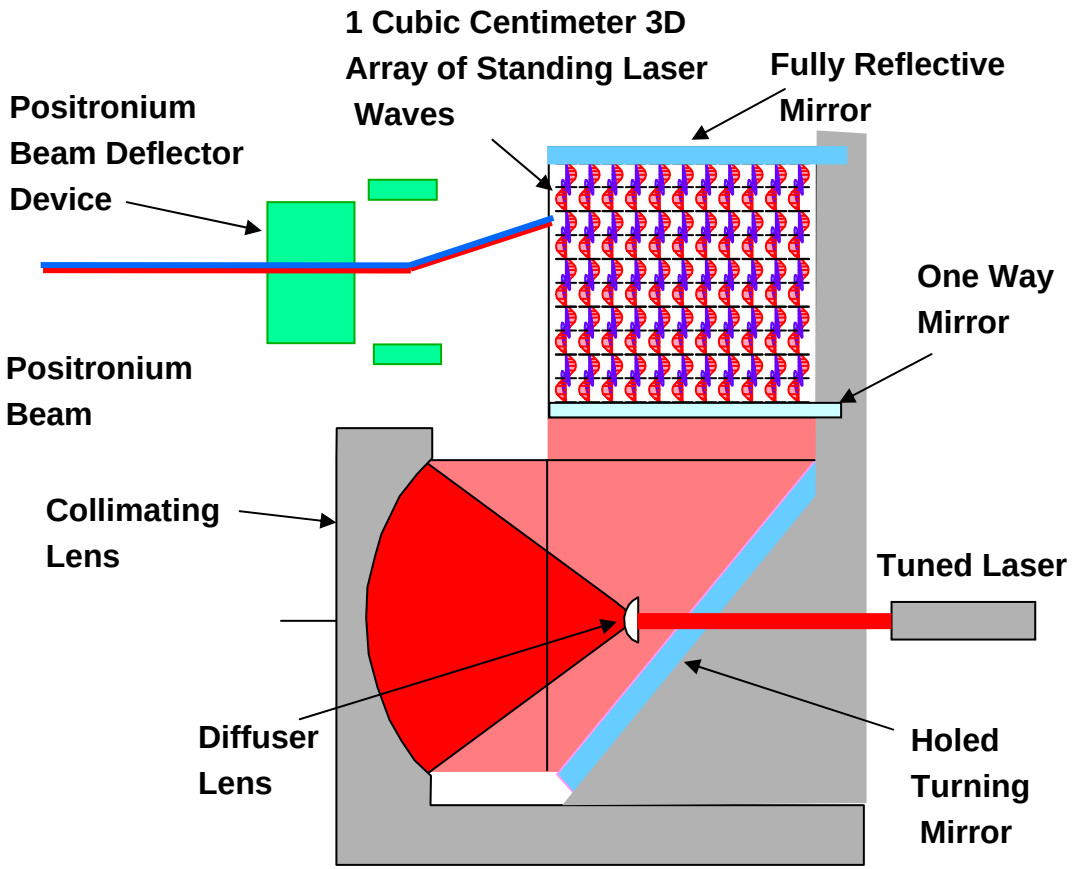
- Lifetimes are a factor of 5 larger than expected for unstable Ps.
- Lifetime times√(V x dipole moment) is a constant of the motion.
- Smaller (~250 nm) stable atom hypothesis agrees with the data.
- These large lifetimes cannot be explained by positron drift.

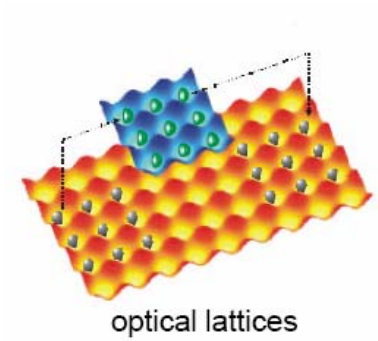
Isometric View of Quantum Dot Positronium Trap



Concept Courtesy of Positronic Research LLC

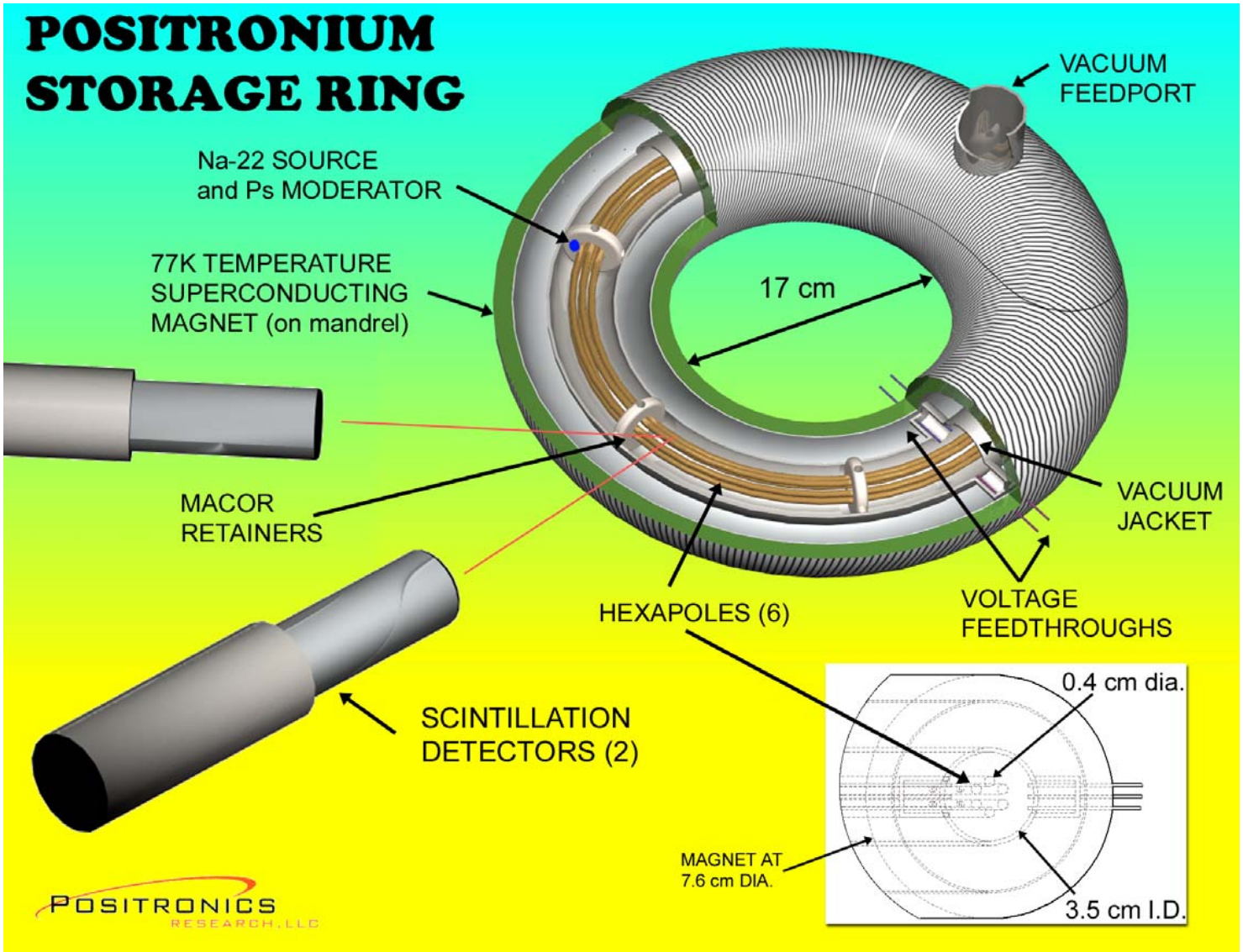
Notional Configuration for Optical Lattice Trap*





Notional Concept Suggested By Ken Edwards, AFRL/MNAV

Schematic of Ring



Positronium Storage Ring

(JON: 30053362)

21 May 03

(Refreshed @ 6/25/03 16:12:12)

	03	04
Award Contract	▲	
Simulate Positronuim Atoms		▲
Complete Design of Positronium Atoms	▲	▲
SBIR Funding ($K)	66	34

- This effort will generate a technique for dynamically storing positronium atoms in a toroidal storage ring

Technology

- Mechanically electric vacuum of configuration to store neutral positronium atoms
- Electrostatic hexapole storage ring with crossed electric and magnetic fields to stabilize ortho-positronium atoms
- Simulate positronium atom motion in storage ring

- World's first attempt to store large quantities of positronium atoms in a laboratory experiment
- If successful this approach will open the door to storing militarily significant quantities of positronium atoms

Why Develop PEC ?

- **Revolutionary Energy Source**

  Energy Density Is Ten Billion Times as That of High Explosive - 180 Mega Joules /Microgram.

  One Gram = 23 Space Shuttle Fuel Tanks of Energy

- **Long Loiter 24/7 Surveillance and Military Missions**
- **Multiple Effects Energy Conversion Devices**

  No Nuclear Residue

- **Single Stage To Orbit Aircraft**
  - **Turbo-ramjet-rocket Exo-Atmospheric Engine**
- **24/7 30 Day missions - Long Endurance Propulsion**

Basic Rev Mun Enabling Technologies

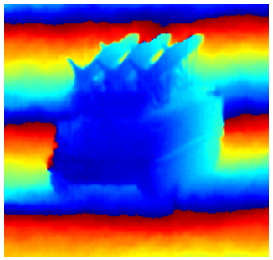
Revolutionary

Multi Spectral

Seekers

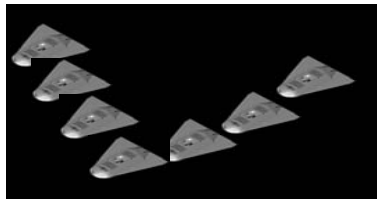
Artificial Intellect Based

Target ID Algorithms



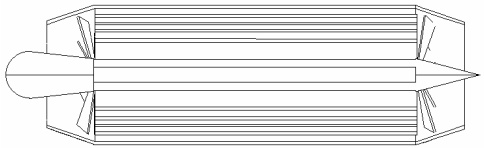
Autonomous

Formation Flying



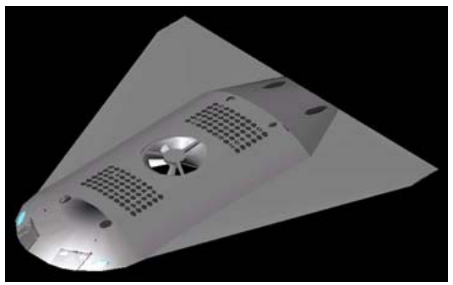
Positron Energy Conversion

Turbo Ramjet Rocket Propulsion

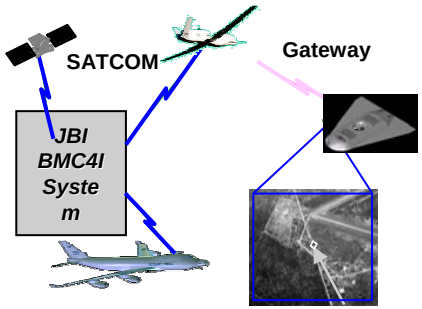


Near Zero CEP Accuracy

24/7/30 Stealthy Search and Destroy Munition



Data Link w/AFRL/IF



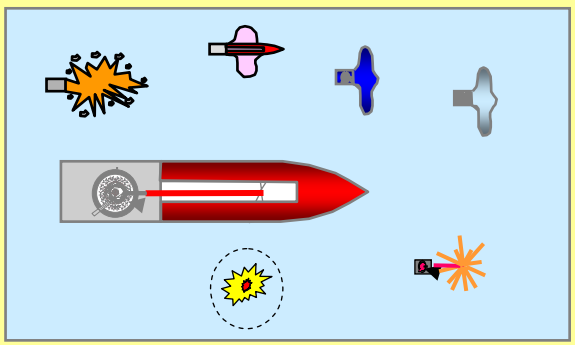
Micro Platforms

Enhanced Survivability

Stealthy Compact Lifting Fan Airframe

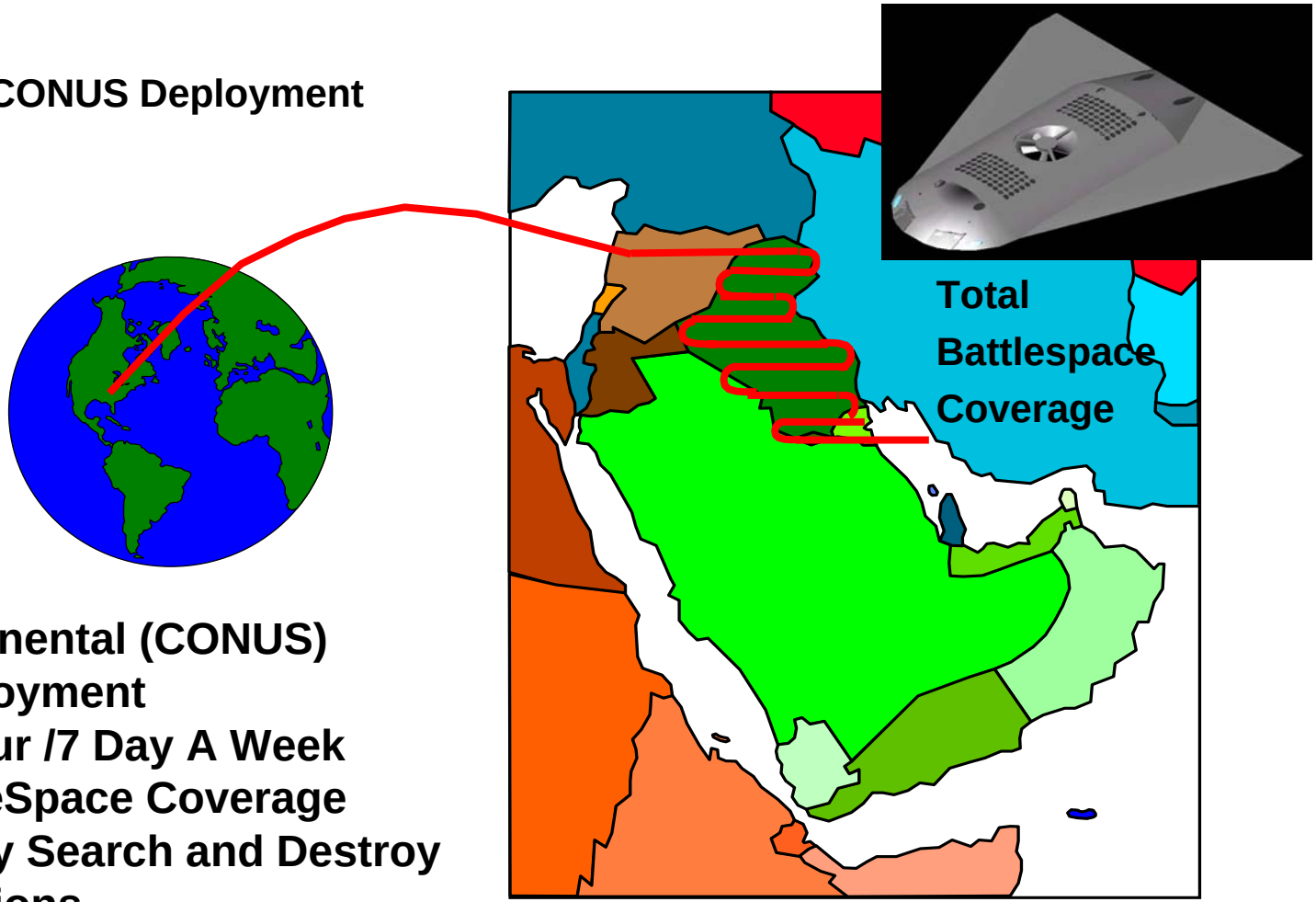
Next Generation Guidance

PEC Based Dial-a- Yield Warhead



24/7 Battlespace Coverage

CONUS Deployment

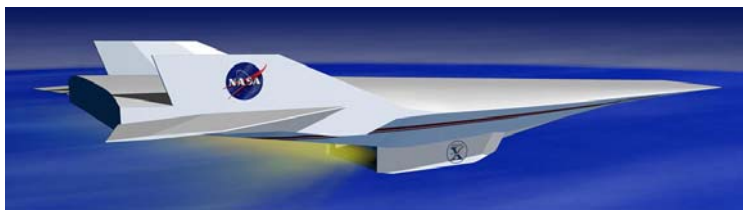


- Continental (CONUS) Deployment
- 24hour /7 Day A Week BattleSpace Coverage
- 30 Day Search and Destroy Missions
- Connected with BattleSpace Internet

Power and Propulsion From Positrons

Current Single Stage Reusable Vehicle (SSRV) Technology

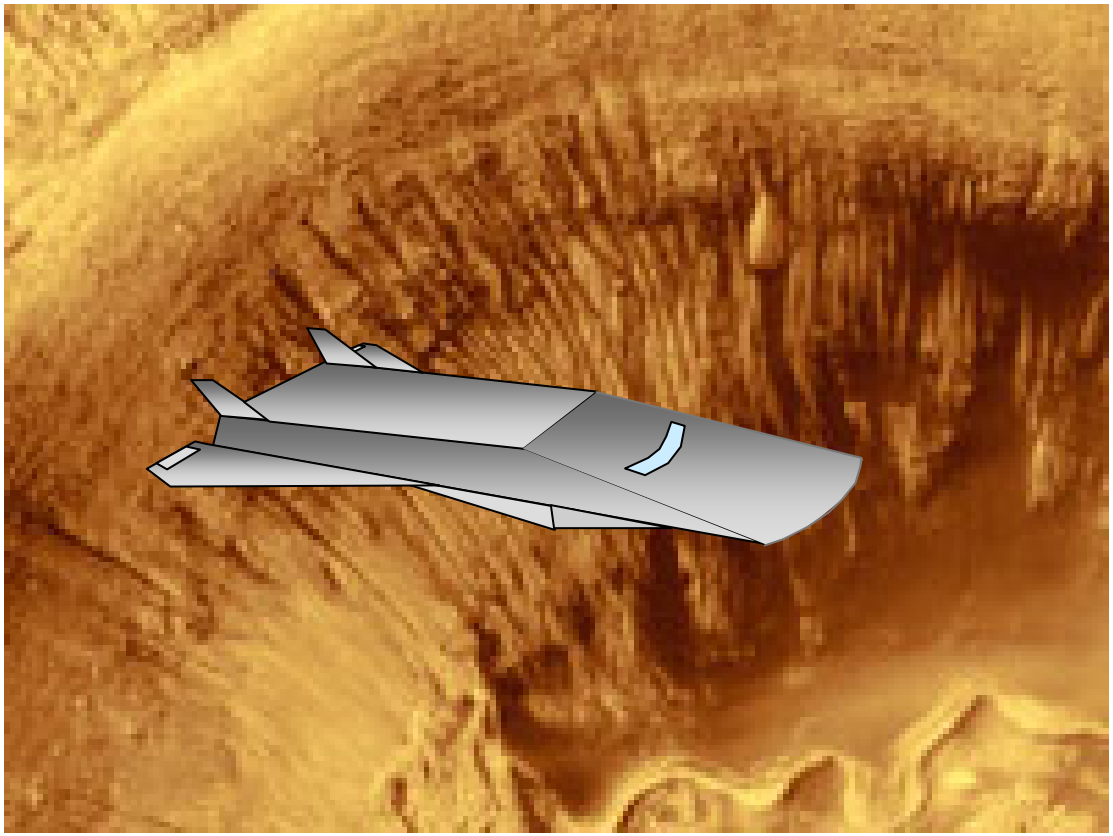
- **The Space Shuttle uses multi-staging to minimize propellant mass (2 x10^6 kg, overall).**
- **A single-stage reusable vehicle (SSRV) requires air-breathing technology to offset increased mass and allow horizontal launch.**
  - **Combination engines include TurboRamjets, Scram Jets, Rockets**
  - **Gross Low Orbit Weights (GLOWs) typically range from 250 to 700 Mg**
  - **Beyond state-of-the-art technology is required for chemical propulsion-based systems.**



A Revolutionary Positron-Based SSRV Vehicle for Application to Human Exploration and Development of Space

Kirby J. Meyer, John D. Metzger, Gerald A. Smith
Synergistic Technologies, Inc. Los Alamos, NM 87544
Presented at the Advanced Space Propulsion Workshop, Huntsville, AL April 2-6 2001

Conceptual Drawing



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Mass Comparison

HTHL Blended-Body

VEHICLE COMPONENT	*MASS (KG)*
Structure	25,700 kg
Thermal Protection	12,300 kg
Propulsion (4 engines)	14,900 kg
Electronics	7,600 kg
Total Dry Mass	60,500 kg
15% Margin + Unus.Prop	11,400 kg
Payload	11,340 kg (25,000 lb)
Burnout Mass	83,200 kg
Total Propellant	368,300 kg
GLOW	451,600 kg (995,500 lb)

*From NGC report to Kaiser-Marquardt for HTHL blended-body SSTO engine, "Vision Vehicle Final Report," April 30, 1998.

STI Positron-assisted TRJ, R configured SSRV

VEHICLE COMPONENT	*MASS*
Total Dry Mass	60,500 kg
15% Margin + Unus. Prop	11,400 kg
Payload	11,340 kg (25,000 lb)
Burnout Mass	83,200 kg
Total Propellant	176,000 kg
GLOW	259,000 kg

*Assumes no bipropellants used during turbojet and ramjet phases of mission, and the dry mass is approximately the same after reducing LOX/LH tank mass and surrounding structure and increasing ramjet engine size.

Summary

- The Air Force is pursuing Revolutionary Energy Solutions for Future Energy needs
- Proof of Principle Experiments are Being Conducted
- Breakthrough Theoretical Predictions may open door to High Density Energy Storage
- We Need your help

Graduation Exam for Humanity

Will we get out of the Gravity well or not.

**"[There is the struggle for existence for all things.
All about us is war: the war of life to survive in spite of every physical law that decrees its death. Why do we fight? This is the true war. Some of us drift into the ranks without banners, without slogans, without heroism. There are no individual prizes to be won except for the feeling that one's task was well done.
To become the type of person that one respects is almost impossible, It requires a discipline that is too often dying to self. The eternal war is fought again in miniature in everyone' heart.]"**

This quote was taken from "Live With Lightning " by Mitchell Wilson and modified to suit the context of the NIAC Symposium