# Frontiers Panel – White Papers
## *New Research Opportunities*


## *C. M. Surko, University of California, San Diego*


We submitted three White Papers:

***Creation and Study of Electron-Positron ("Pair") Plasmas***
**C. M. Surko and T. S. Pedersen**

*Plasma Physics Drivers for Physics with Antimatter*
C. M. Surko and Joel Fajans

*Vortex Dynamics in Externally Driven Flows*
*Studied Using Electron Plasmas*
N. C. Hurst, J. R. Danielson, Phil Morrison and Surko

# Frontiers Panel – White Papers
## *New Research Opportunities*

***Creation and Study of Electron-Positron ("Pair") Plasmas****

*** Subcommittee: Turbulence and Transport?**
**(checked all secondary ones too)**

*Plasma Physics Drivers for Physics with Antimatter*

*Vortex Dynamics in Externally Driven Flows*
*Studied Using Electron Plasmas*

→ **These are New Research Frontiers driven by new experimental capabilities.**

**Analogies in condensed matter physics:**
**carbon nanotubes**
**cold atoms in optical lattices**

# Why Study Electron-Positron ("Pair") Plasmas?

**Novel phenomena for $m_+ = m_-$, $T_+ = T_-$ and $n_+ = n_-$**

- Acoustic mode heavily damped (absent)
- Faraday rotation absent
- Three-wave decay processes absent
- Very strong nonlinear growth and damping processes
- Prominent solitary wave behavior
- Turbulence and reconnection behavior also different

Tsytovich & Wharton, Comm. on Pl. Phys. (1978)

**Remarkable stability properties**

(P. Helander, PRL 2014)

**Astrophysics (> 1000 theory papers!)**

Potentially relevant to:

- Gamma ray bursts
- Pulsar winds
- Jets from active galactic nuclei

Complementary work
on pair-ion plasmas (e.g.,$C_{60}^{\pm}$)
Oohara and Hatakeyama, **PRL** (2003)

**Equal mass ions, easily/strongly magnetized**

# Stability of e+/e- pair plasmas

PRL **113,** 135003 (2014) PHYSICAL REVIEW LETTERS week ending 26 SEPTEMBER 2014

**Microstability of Magnetically Confined Electron-Positron Plasmas**

P. Helander
*Max-Planck-Institut für Plasmaphysik, 17491 Greifswald, Germany*
(Received 25 June 2014; published 24 September 2014)

It is shown that magnetically confined electron-positron plasmas can enjoy remarkable stability properties. Many of the microinstabilities driving turbulence and transport in electron-ion plasmas are absent if the density is so low that the Debye length is significantly larger than the gyroradius. In some magnetic configurations, almost complete linear stability may be attainable in large parts of the parameter space.

DOI: 10.1103/PhysRevLett.113.135003 PACS numbers: 52.27.Ep, 52.35.Qz, 52.55.-s

*"the electrostatic instabilities causing turbulence and transport in magnetically confined electron-ion plasmas are largely absent in low-density electron-positron plasmas."*

*P. Helander, PRL (2014)*

# Why can e+/e- plasma exist anyway?

## Annihilation is weak so pair plasmas long lived.

**positronium formation:**
Slow unless the
temperature is very low

**“direct” $e^+$ - $e^-$ annihilation:**
1 day at $n = 10^{10}$ $cm^{-3}$

**annihilation on neutral background** (not shown)**:**
100 s in $10^{-6}$ torr $N_2$

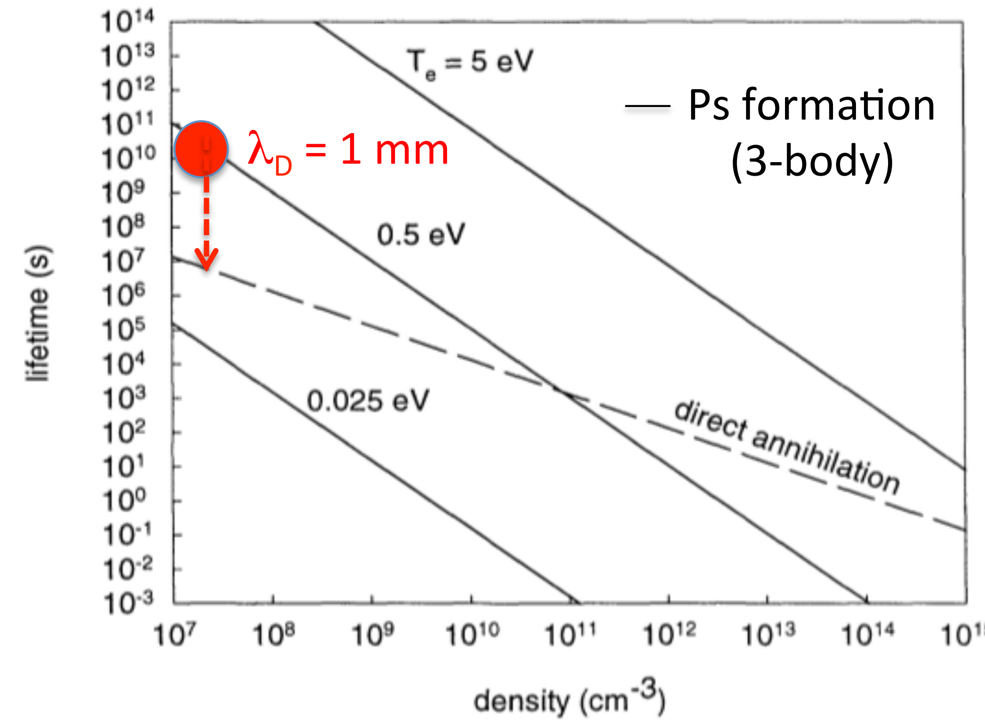
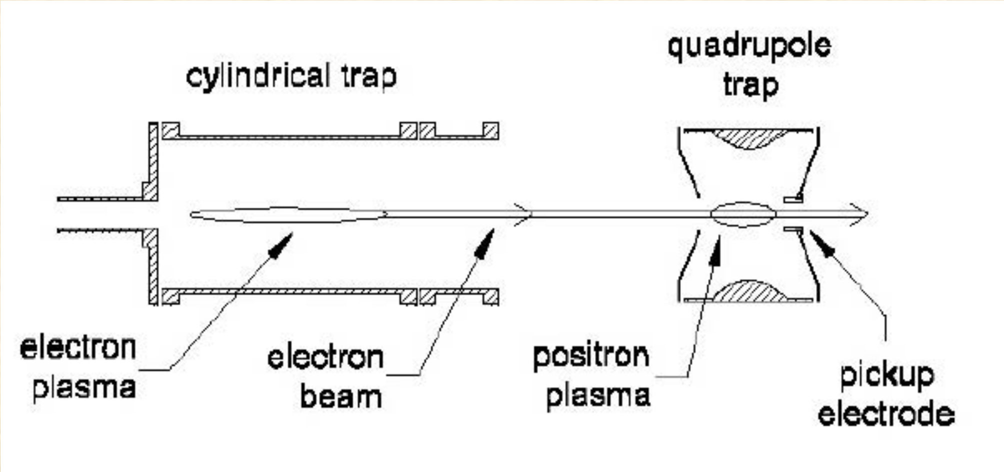


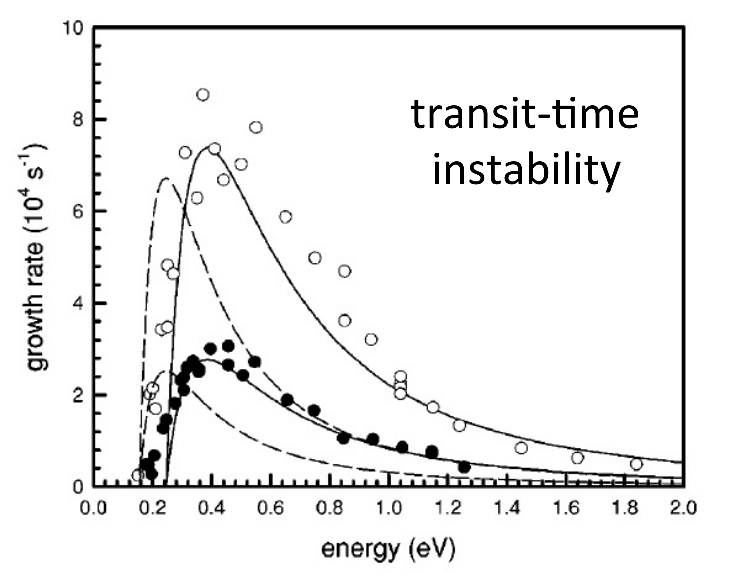

**FIGURE 2.** Electron-positron plasma lifetime due to direct annihilation (dashed line) and positronium formation (solid lines) as a function of plasma density.

Greaves and Surko AIP 2002

# Electron-beam Positron-plasma Instability



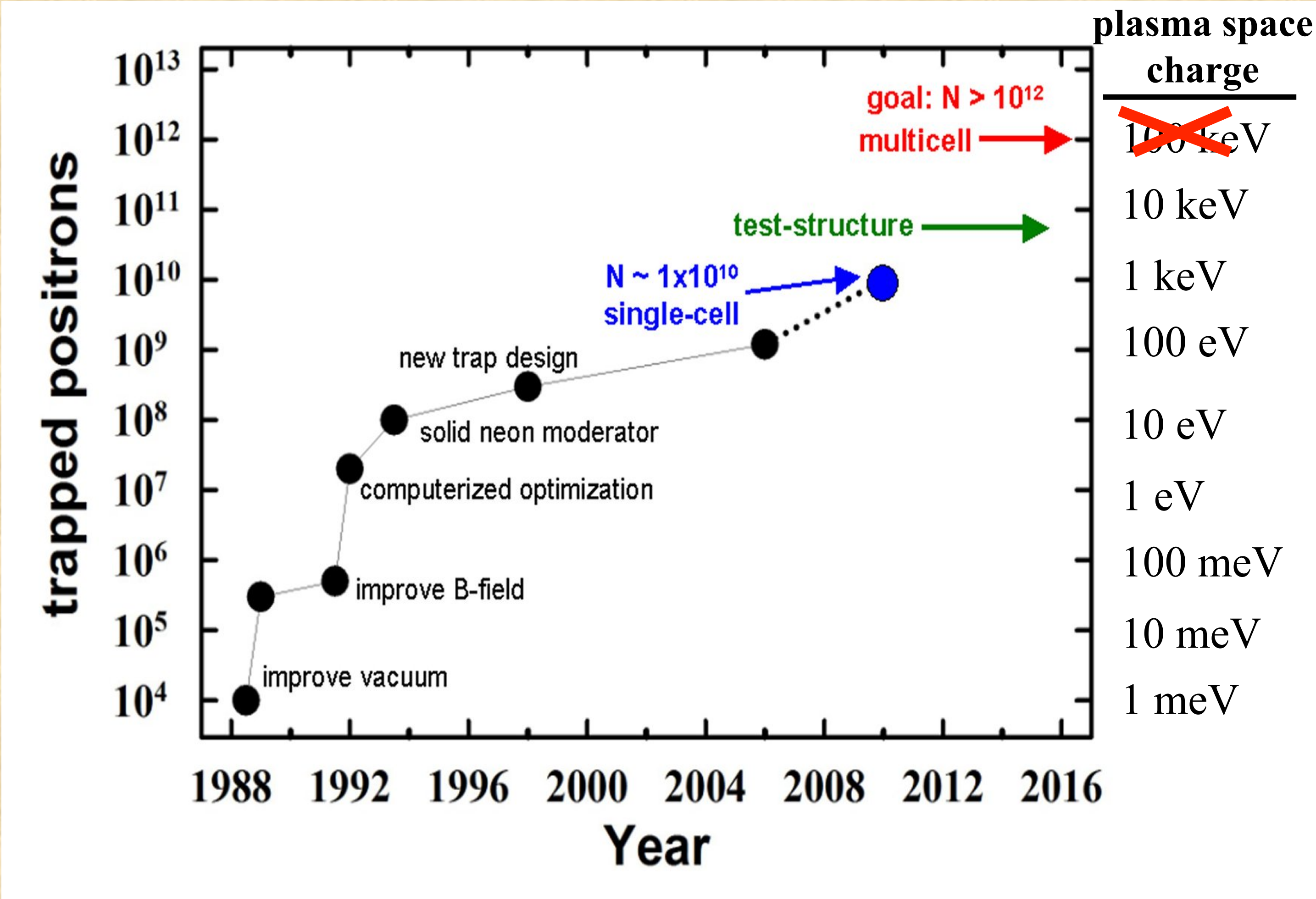

Studied two-stream and transit-time instabilities




Greaves PRL 1995
Gilbert PP 2001

# No studies yet of simultaneously confined $e^+$ - $e^-$ plasmas

# Pair-Plasma Studies – Why Now?




**Need ≥ $10^9$ trapped positrons**

**Improvements in positron sources, trapping and manipultion make that possible.**

# Possible Confinement Schemes

Penning Paul Trap
Magnetic Mirror[1]
Stellarator[2]
Levitated Magnetic Dipole

1. Gibson PRL 1960; Boehmer and Rynn 1995   2.Pedersen et al., 2003 - 2012

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Not discussed: Pair plasmas made with high intensity lasers.[3]

(Detailed physics studies are difficult due to lack of long term confinement.)

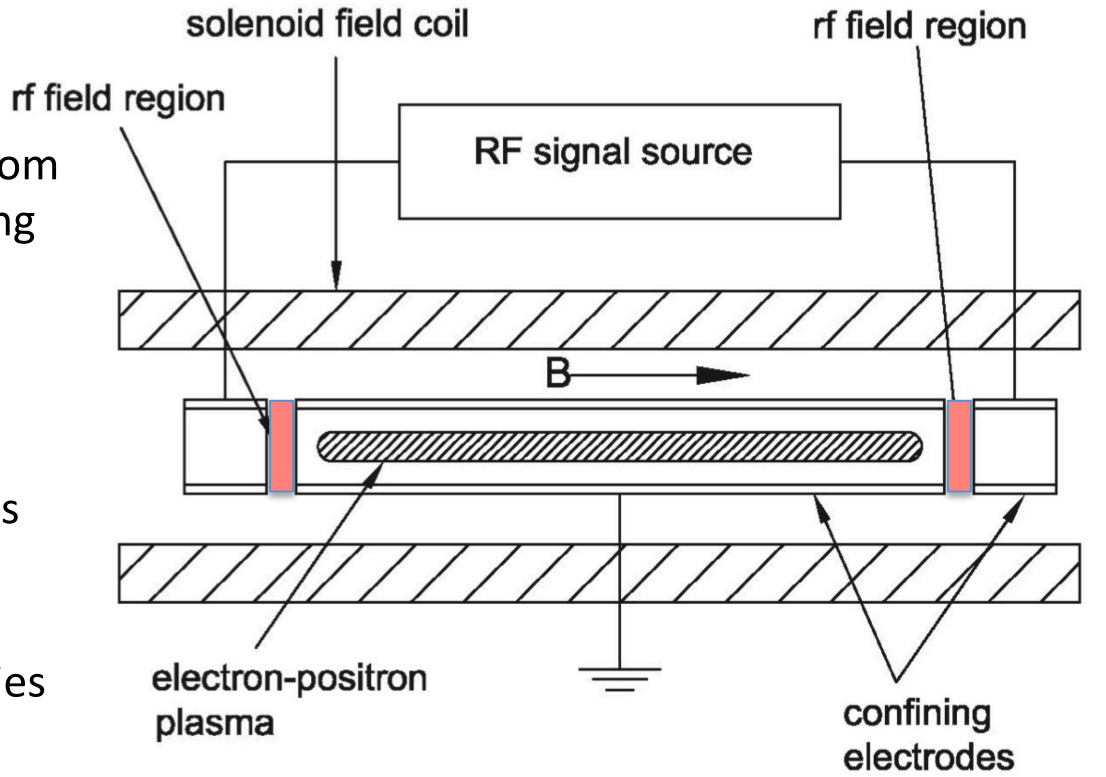
3. G. Sarri, Nat. Com. 2014; H. Chen, PRL 2015

# Penning-Paul Trap

Easy loading from nested Penning traps

Dump to visualize radial profiles

Antennas for wave studies




| | |
|---|---|
| **N** | **$10^9$** |
| B | 0.1 - 5 T |
| **n** | **$10^7$ cm$^{-3}$** |
| **T** | **0.5 eV** |
| $r_p$ | 0.5 cm |
| $L_p$ | 30 cm |
| $V_{rf}$ | 100 V |
| $f_{rf}$ | 100 MHz |
| $V_{rf}^{eff}$ | 5 V |

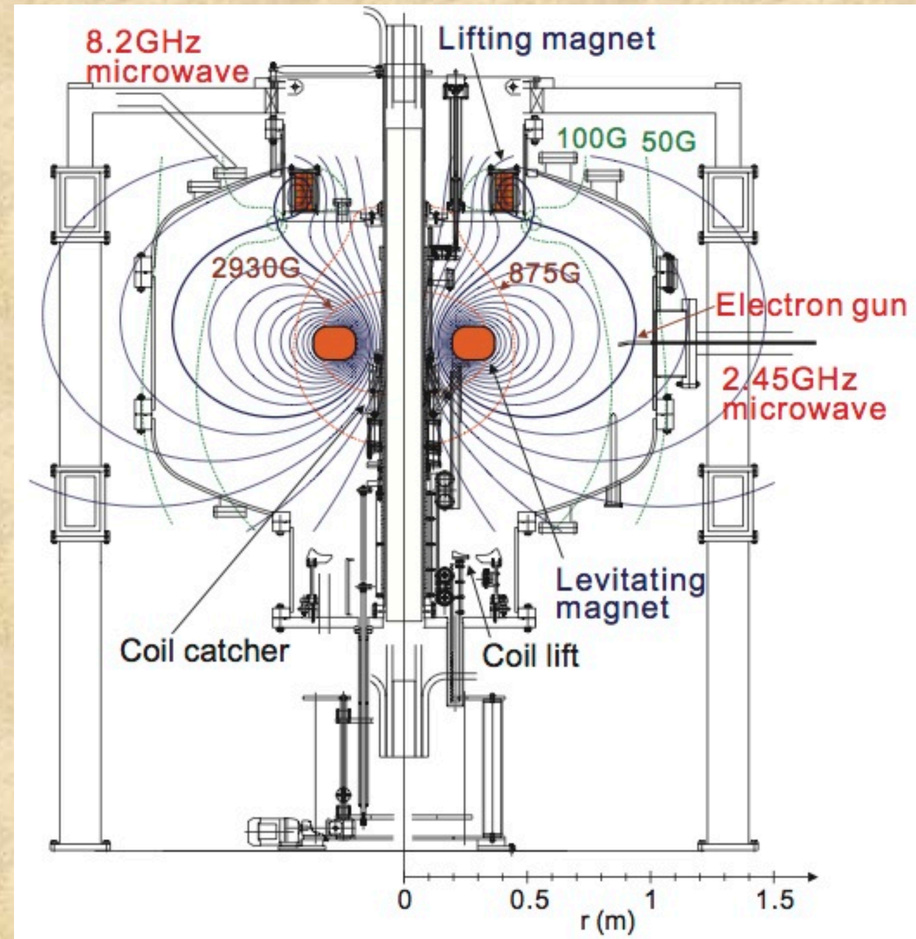
Transport due to
Positron/electron vortex motion
*ala* Dawson-Okuda?

Gas cooling: $10^{-6}$ torr $CO_2$

Greaves & Surko AIP 2002

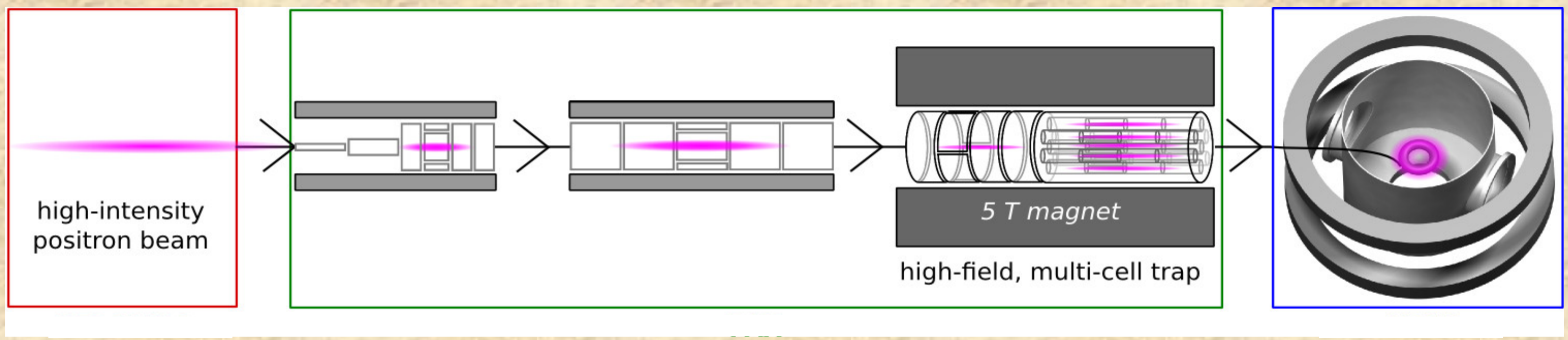
# Levitated Magnetic Dipole RT 1

$n = 10^5\ cm^{-3}$
$e^-$ confined for 300 s




Yoshida PPCF 2013

# Greifswald/Munich/UCSD Levitated Dipole Project[1]




| | | | | |
|---|---|---|---|---|
| Munich reactor beam $10^9$ $e^+$/s* | 2-stage accumulator | short-term storage | store $10^{10} – 10^{12}$ $e^+$ | levitated dipole trap |

* Similar intense beam available at North Carolina State University.

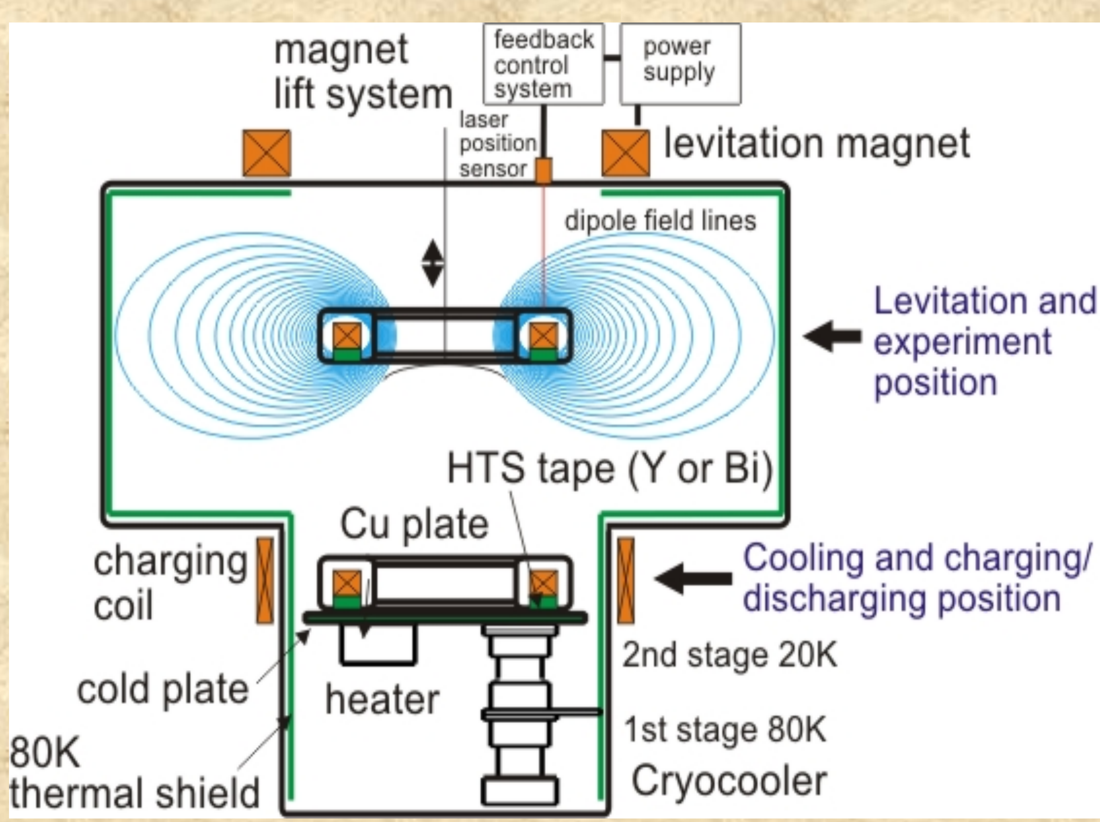
1. Team leader: T. S. Pedersen

# Levitated Dipole Design

Diagnostics
- Annihilation rate for density
- Annihilation on pellet for radial profile
- Antennas for wave studies

V ~ 5 liter

20 cm




H. Saitoh J. Phys. B Conf. Ser. 2014

T. S. Pedersen NJP 2012

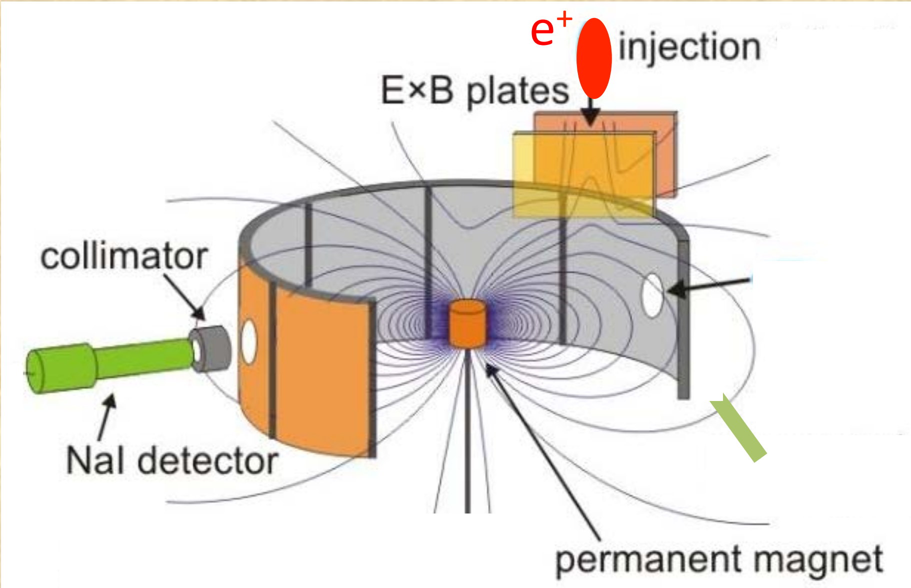
# Levitated Dipole Experiment - Challenges

Need lots of positrons $N > 10^9$

Need efficient injection mechanism
    E x B plates
    Ps atom formation, then laser ionize

Maintain low temperature, $T \leq 1$ eV
        (cyclotron cooling)

# Confining $e^+ - e^-$ (pair) Plasma in a Levitated Magnetic Dipole

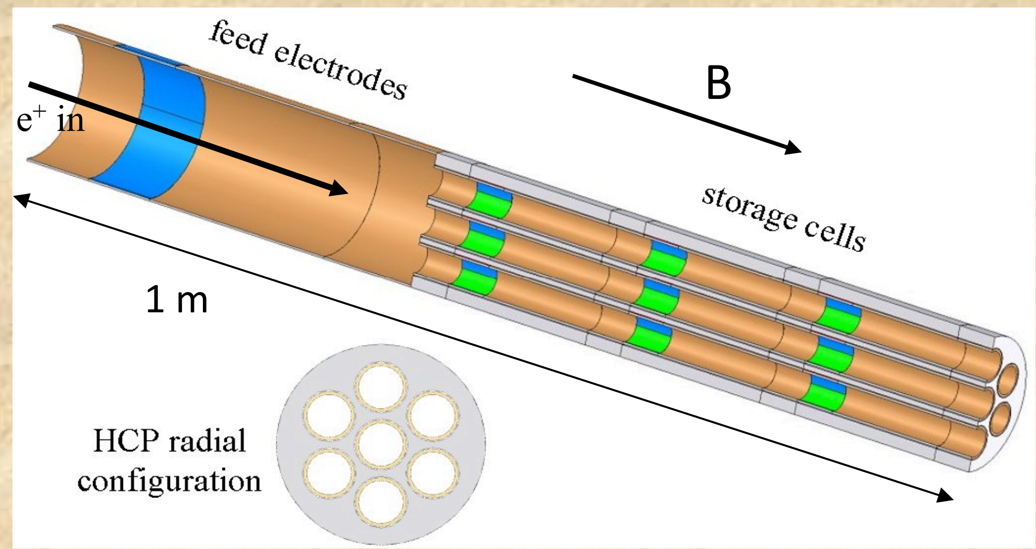



test injection experiment begun 2015

H. Saitoh, JP Conf. Ser. 2014
T. Sunn Pedersen, NJP 2012

# How Do We Get N > $10^9$ Positrons?

## Solution: Shield Parallel Cells with Copper Electrodes – a multicell trap for $10^{12}$ positrons




3 banks of 7 cells with $5 \times 10^{10}$ $e^+$ each

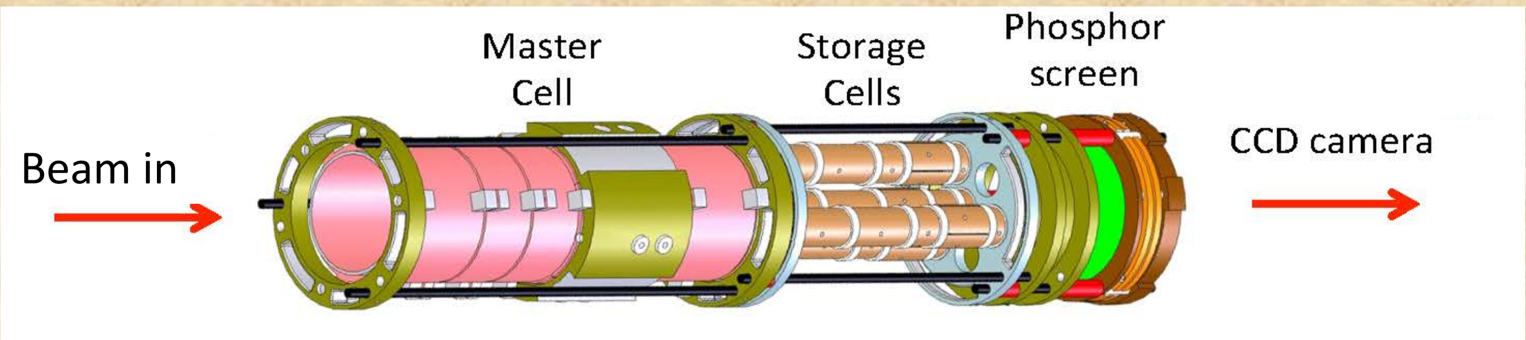
1 kV confinement potentials

Surko, JRCP '03

Danielson, PP '06

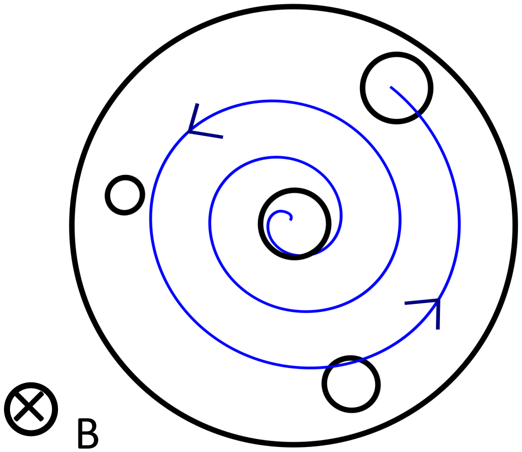
# Multicell Trap Test Structure

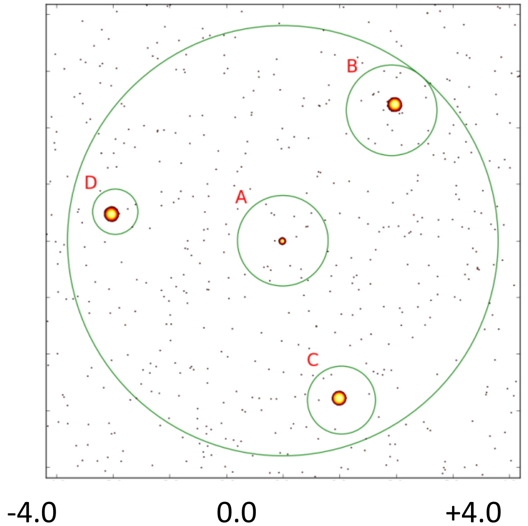
3 off-axis cells




- ≥ 50% transfer efficiency
- Need to demonstrate confinement of kV space charge off axis

diocotron-mode autoresonance



# Summary
# Creation and Study of Electron-Positron ("Pair") Plasmas

Pair plasmas are predicted to have novel/unique properties
- Non-linear behavior
- Transport & confinement

**<u>We have the tools to make this a realizable Frontier Research Area.</u>**

Further development of high-flux positron sources will greatly facilitate pair plasma experiments (relativistic plasmas?)

Potential impacts
- Fundamental plasma processes
- Astrophysics relevance
- Antimatter captures the lay public's imagination