

# ELECTRON POSITRON PLASMA

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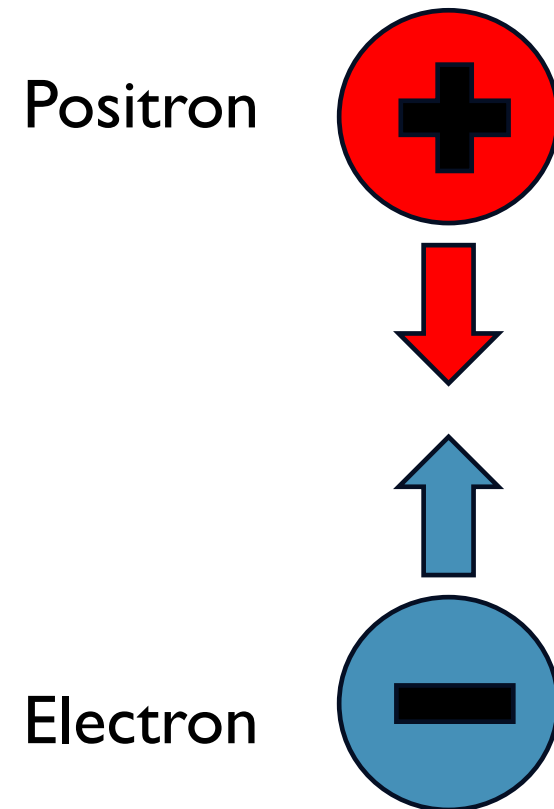
PROSEMINAR PLASMA PHYSICS

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- What is an EPP?
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# WHAT IS AN EPP?

- Particle and antiparticle plasma
- Same properties besides charge and magnetic moment
- Accumulation method for antiparticles
- Unique physical properties



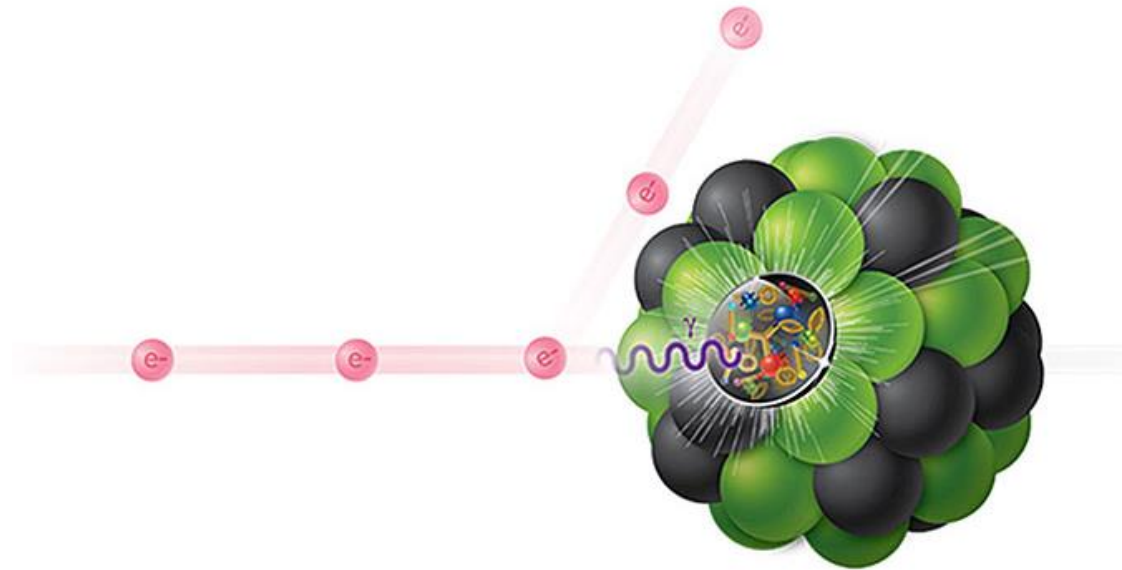


# PROPERTIES



# MASS DIFFERENCE

- Normal plasmas:
  - Mass difference causes instabilities
  - Fast and slow phenomena
  - Different energy exchange
- No mass difference in EPPs

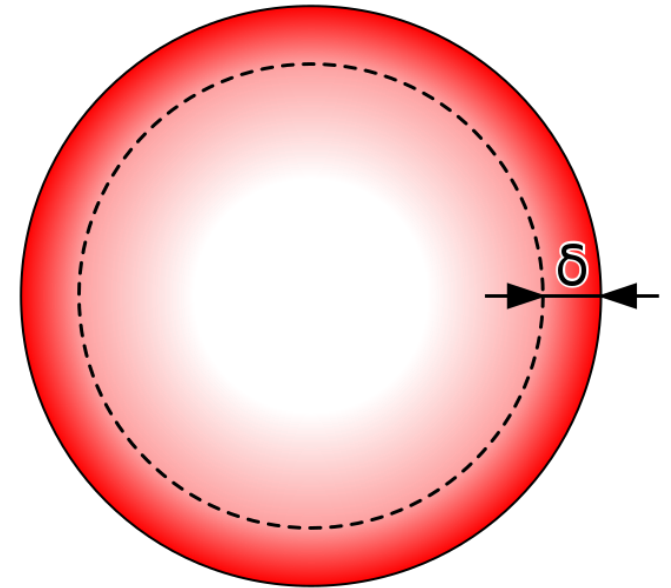


(<https://www.bnl.gov/newsroom/news.php?a=217396>)

# SYSTEM SIZE, DEBYE LENGTH, PLASMA SKIN DEPTH

- Plasma skin depth: depth that EM radiation can penetrate
- Plasma frequency: frequency of electron oscillation
- In EPPs  $\sqrt{2}\omega_{pe}$
- Dispersion relation:  $\omega^2 = 2\omega_{pe}^2 + 3v_{Te}^2 k^2$

$$l_S = \frac{c}{\omega_{pe}}$$



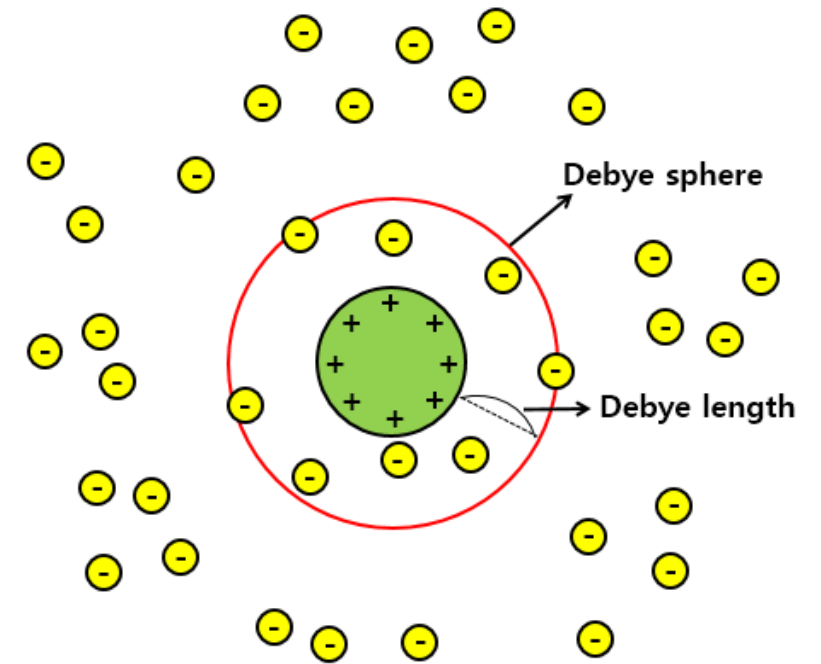
([https://en.wikipedia.org/wiki/Skin\\_effect](https://en.wikipedia.org/wiki/Skin_effect))

# SYSTEM SIZE, DEBYE LENGTH, PLASMA SKIN DEPTH

- Debye length: distance at which electrostatic potential can be neglected
- In EPPs positrons participate in screening

- $\frac{e\phi}{k_B T}$  not negligibly small  $\lambda_D = \sqrt{\frac{\epsilon_0 \kappa T_e}{2n_e e^2}}$

$$\frac{e}{k_B T} \frac{enL^2}{6\epsilon_0} \approx 1 \quad \longrightarrow \quad \lambda_D \approx \frac{L}{\sqrt{6}}$$



(<https://marriott.tistory.com/58>)

# SYSTEM SIZE, DEBYE LENGTH, PLASMA SKIN DEPTH

$n_e$ ( $\text{m}^{-3}$ )	T	$\lambda_D$ (mm)	system
$10^{11}$	0.1 eV	10	ionosphere
$10^{12}$	1 eV	5	low-temperature electron/positron plasma
$10^{22}$	50 MeV	0.4	laser-produced electron/positron plasma
$10^{20}$	10 keV	0.1	MCF plasma
$10^{31}$	10 keV	$10^{-7}$	ICF plasma (imploded)

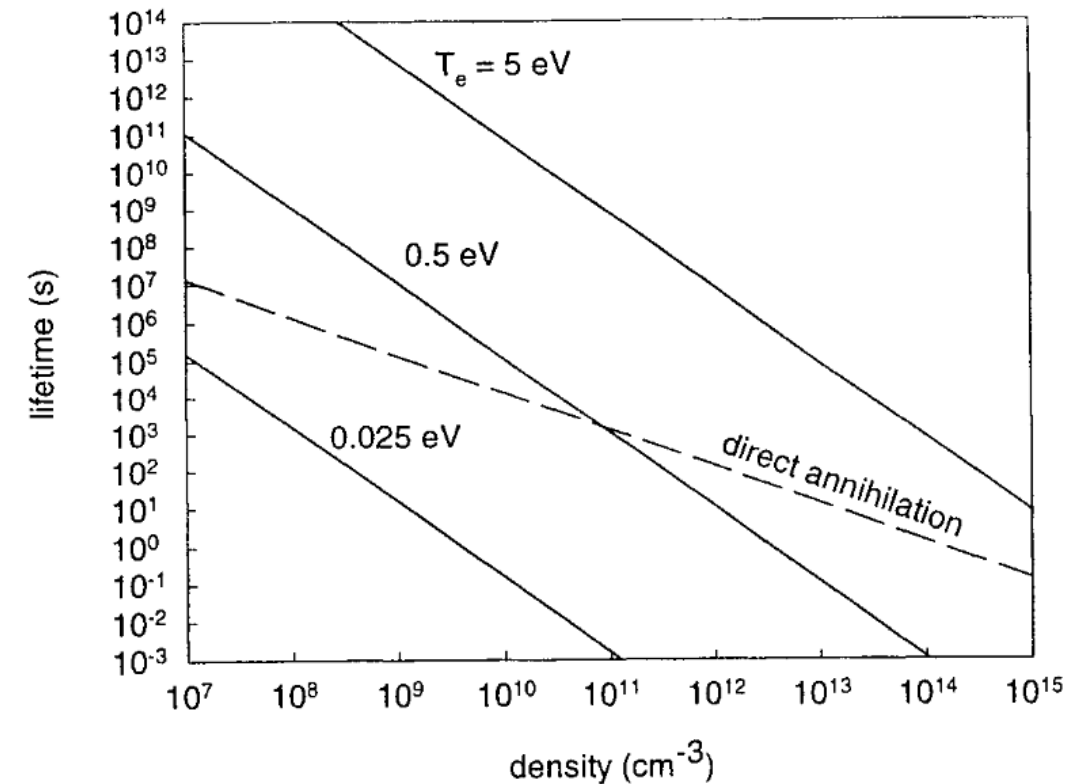
$n_e$ ( $\text{m}^{-3}$ )	$l_s$
$10^{12}$	5.3 m
$10^{12}$ (e+/e- plasma)	3.8 m
$10^{20}$	0.53 mm
$10^{21}$ – $10^{22}$ (e+/e- plasma)	0.1–0.4 mm
$10^{22}$	53 $\mu\text{m}$
$10^{25}$	1.7 $\mu\text{m}$

(E.V. Stenson et al., Journal of Plasma Physics, 2017)



# COLLISIONAL EFFECTS

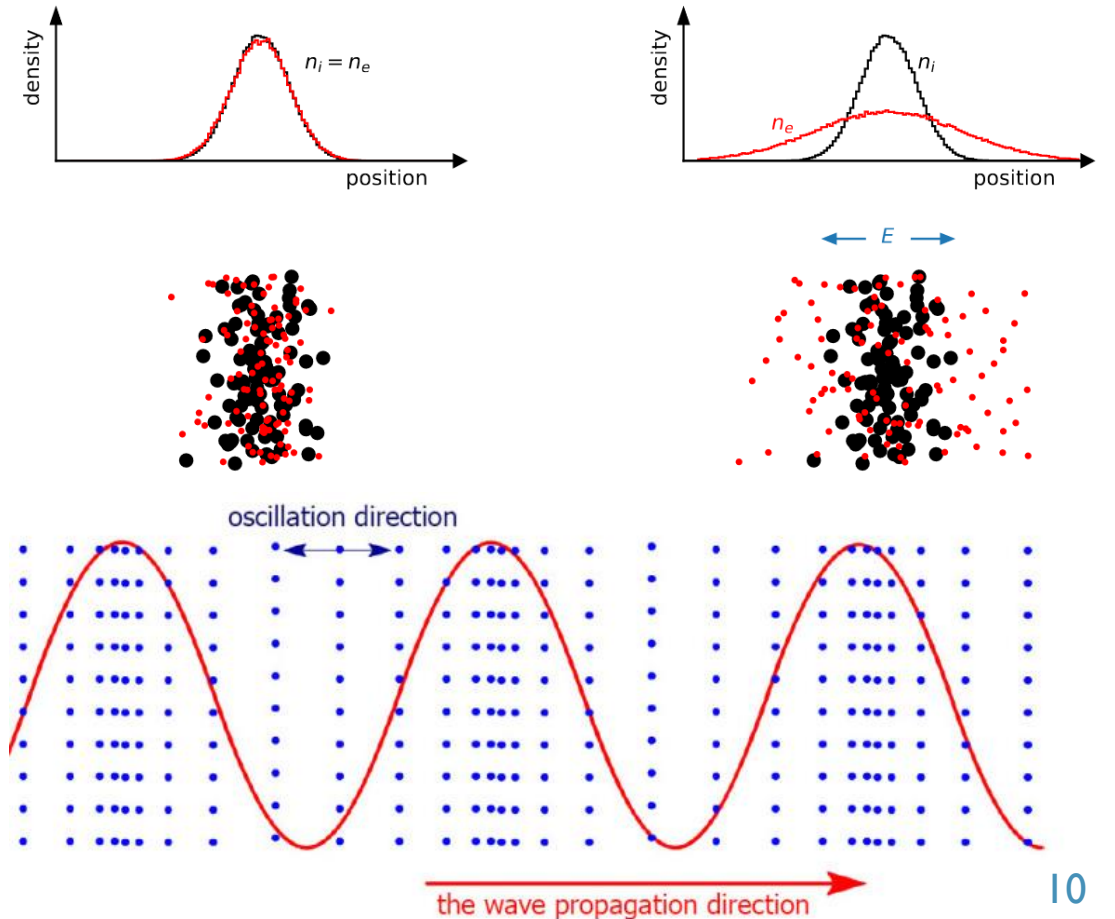
- Creation and annihilation of particles
- Neglectable if plasma frequency higher than collision frequency
- Annihilation useful for diagnostics
- Positronium can form



# ACOUSTIC WAVES

- Wave is driven by electron pressure and ion mass
- Pressure perturbation causes charge separation
- Electric field is created
- Acoustic ion wave forms
- No charge separation arises in EPPs due to mass symmetry

$$\frac{n_e}{n_0} = e \frac{e\phi}{k_B T}$$

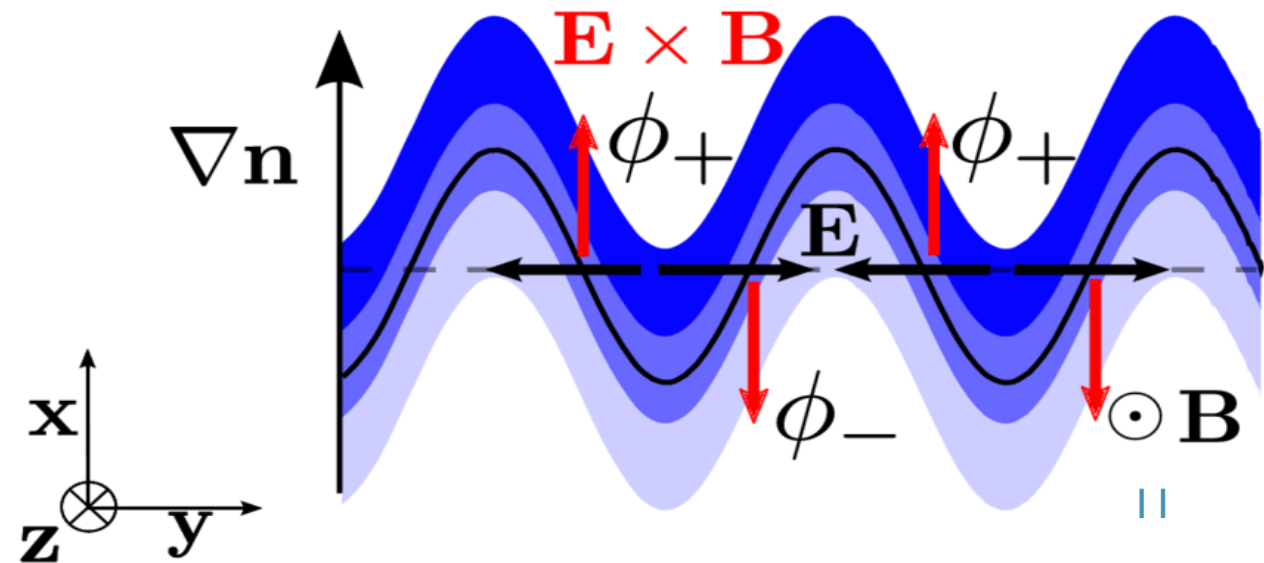


# DRIFT WAVES

- Gradient in thermal pressure leads to drift wave
- Component of electric field perpendicular to magnetic field produced drift

- Universal instability

- EPPs don't have drift waves



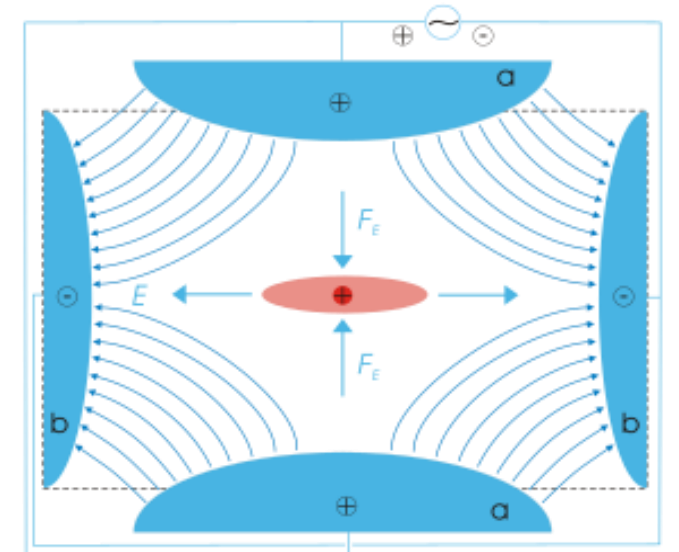
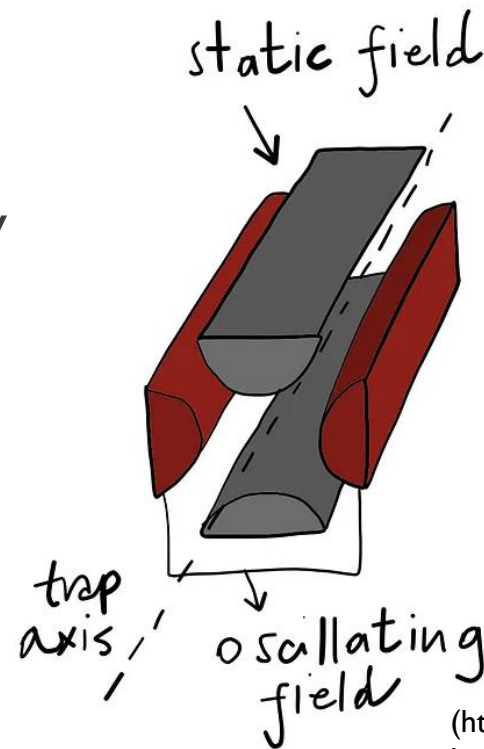
([https://www.researchgate.net/figure/Drift-wave-mechanism\\_fig3\\_262364216](https://www.researchgate.net/figure/Drift-wave-mechanism_fig3_262364216))

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# CONFINEMENT

# PAUL TRAPS

- Dynamic quadrupole field
- Two oscillating fields, one static
- Ions pulled up and down and pushed in radially
- Then pulled out radially and pushed in axially
- Slow down positrons before injecting

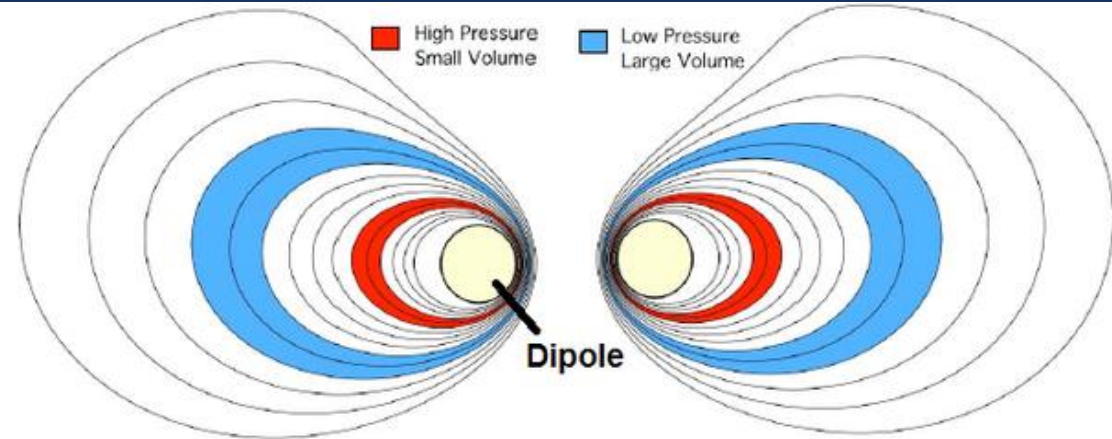


([https://en.wikipedia.org/wiki/Quadrupole\\_ion\\_trap](https://en.wikipedia.org/wiki/Quadrupole_ion_trap))

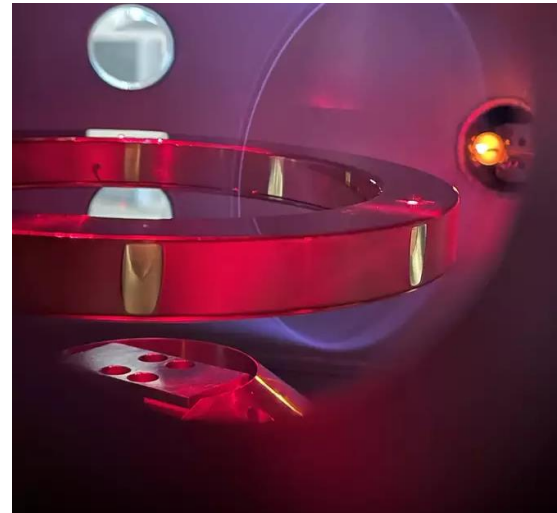
(<https://decarolichiarra.medium.com/a-brief-history-of-ion-traps-for-quantum-information-processing-caa193bc4585>)

# DIPOLE CONFINEMENT

- Considered in the 1960s/70s
- Levitated coil
- Self-organization and stability
- $10^{10}$  electrons confined for 300s



([https://en.wikipedia.org/wiki/Levitated\\_dipole](https://en.wikipedia.org/wiki/Levitated_dipole))



([https://www.ipp.mpg.de/5379974/Levitated\\_Dipole\\_apex](https://www.ipp.mpg.de/5379974/Levitated_Dipole_apex))

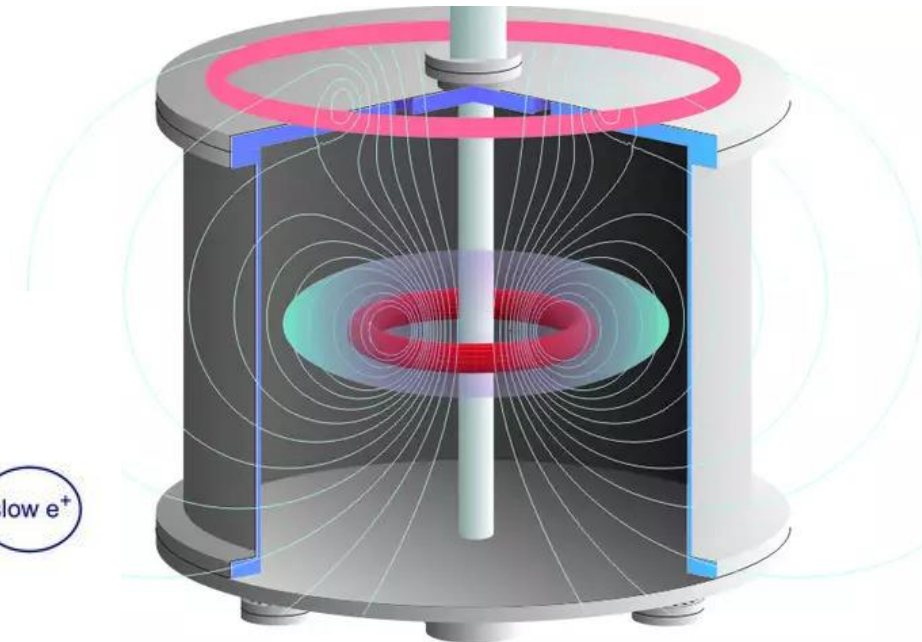
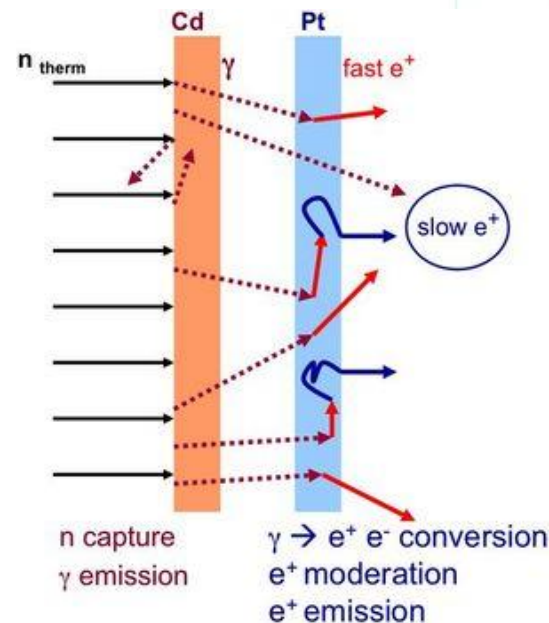
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# CURRENT RESEARCH



# APEX

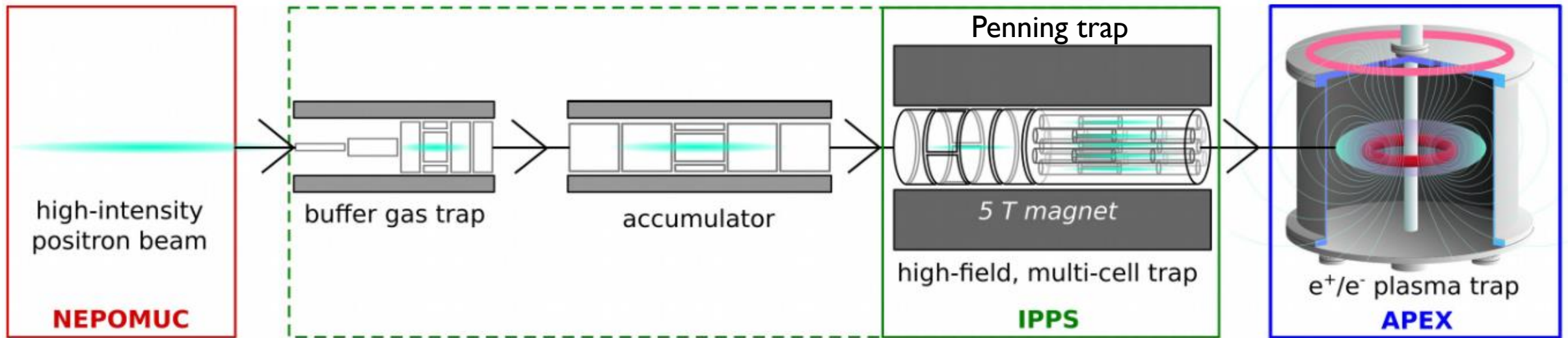
- A Positron-Electron eXperiment at IPP
- Dipole-confined, low-temperature EPP
- $T_e \approx 1\text{eV}$ ,  $n_e \approx 10^{12}\text{ m}^{-3}$ ,  $V \approx 10^{-2}\text{ m}^3$
- NEPOMUC as positron source
- Accumulator is needed



<https://www.ipp.mpg.de/4793936/nwg-19>

(<https://webarchiv.typo3.tum.de/PH/Is-sces/sces/forschung/positron-physics/experimental-facilities/nepomuc/index.html>)





([https://hiddensymmetries.princeton.edu/sites/g/files/toruqf1546/files/stenson\\_-\\_simonssummerschool\\_2019.08.pdf](https://hiddensymmetries.princeton.edu/sites/g/files/toruqf1546/files/stenson_-_simonssummerschool_2019.08.pdf))

Here you can see  
how the ring takes off  
(10x video speed)



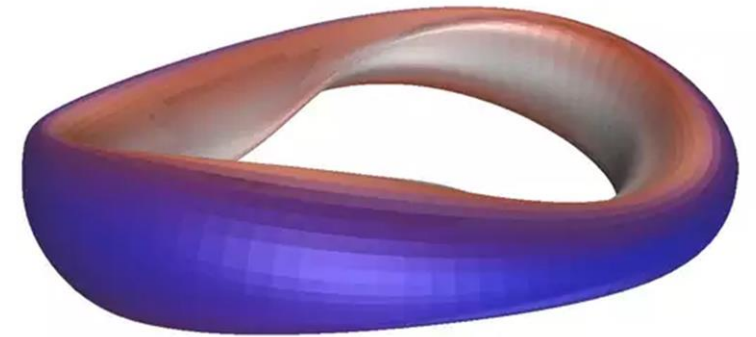
(<https://www.youtube.com/watch?v=WdD8Y8WeE5g>)

# EPOS

- Electrons and Positrons in an Optimized Stellarator
- Similar plasma volume, density and temperature targeted

as APEX

- No levitating coil is needed



(<https://www.ipp.mpg.de/4793936/nwg-19>)



**EPOS**

([https://hiddensymmetries.princeton.edu/sites/g/files/toruqf1546/files/stenson\\_-\\_simonssummerschool\\_2019.08.pdf](https://hiddensymmetries.princeton.edu/sites/g/files/toruqf1546/files/stenson_-_simonssummerschool_2019.08.pdf))

## CONCLUSION

- EPPs are an active research topic
- Worth pursuing
- Strange behavior
- Overlap of astrophysics, antimatter physics and plasma physics

