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Chaos of charged particle orbit in a compact levitated dipole experiment

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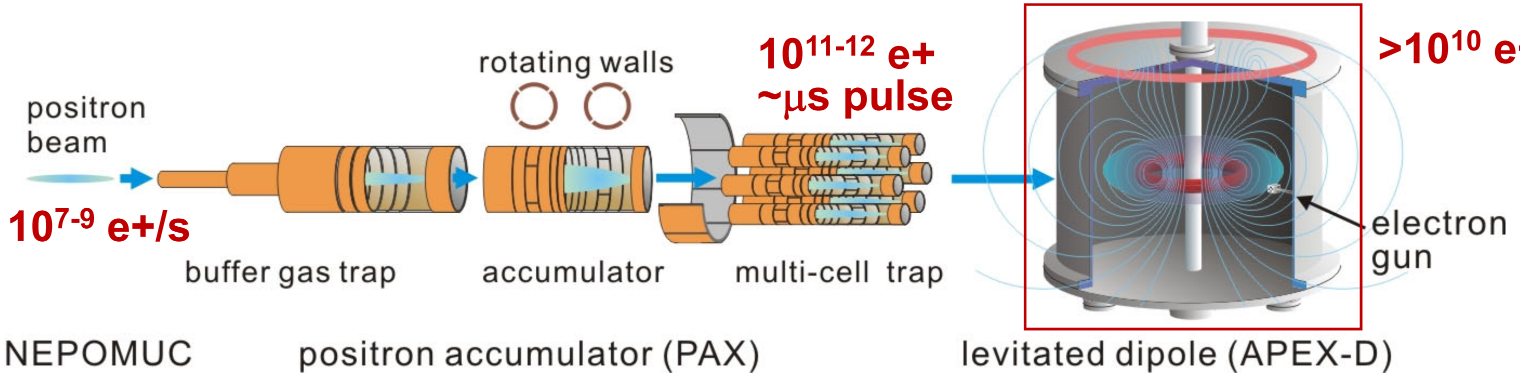
Outline

- Plan and status of Compact Levitated Dipole for electron-positron pair plasmas
- Motivation to study chaotic orbit of positrons (e+s) in CLD
- Mechanism of chaotic orbit in dipole by μ-J coupling (high-energy e+s in RT-1)
  (>~100keV, not straightforward to be conducted in trap experiments)
- Analysis of chaotic orbit of e+/e-s in the planned compact dipole
  - possibility of chaos with low energy (~10eV) e+/e-
  - condition for the μ-J coupling chaotic orbit with low energy particles
  - long flight time of positrons/electrons
- Summary and future work

Background : Compact levitated dipole towards the formation of electron-positron plasma in laboratory

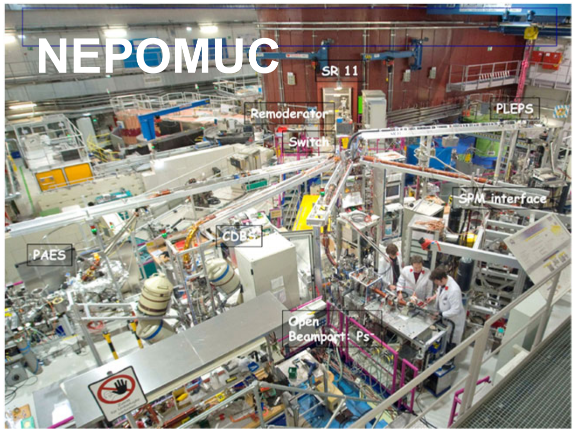
- Creation of electron-positron plasmas

2020 Higaki+ Appl. Phys. Exp. @AIST/Hiroshima
2015 Saitoh+ New J. Phys. @NEPOMUC/IPP/TUM



・unique wave/stabilities as pair-plasmas

・astrophysically equivalent experiment

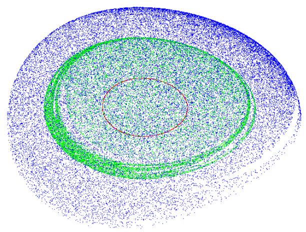


Reactor (FRM-II) based e+ source

2012 Hugenschmidt+, New J. Phys.

- Application of chaotic orbit in levitated dipole

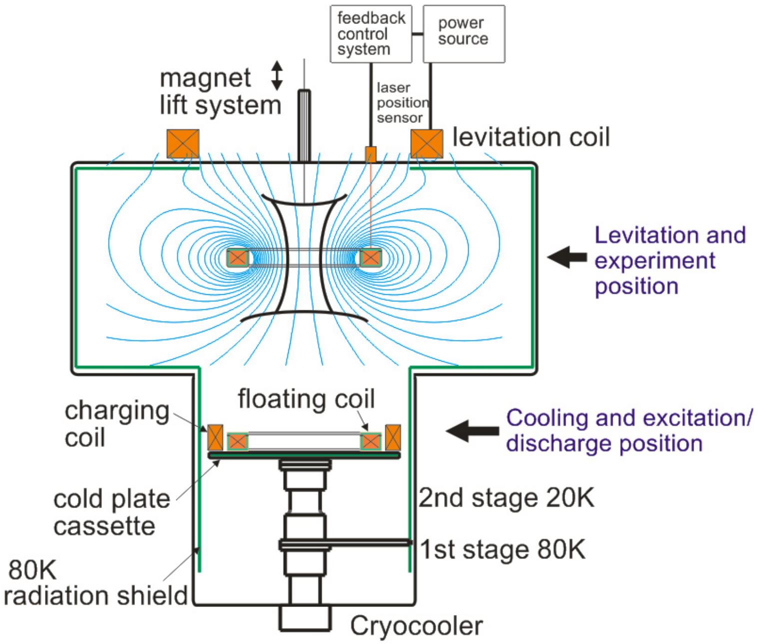
  ・chaos-induced transport
  ・injection scheme (long orbit)
  ・particle mixing (of e+/e- in trap)

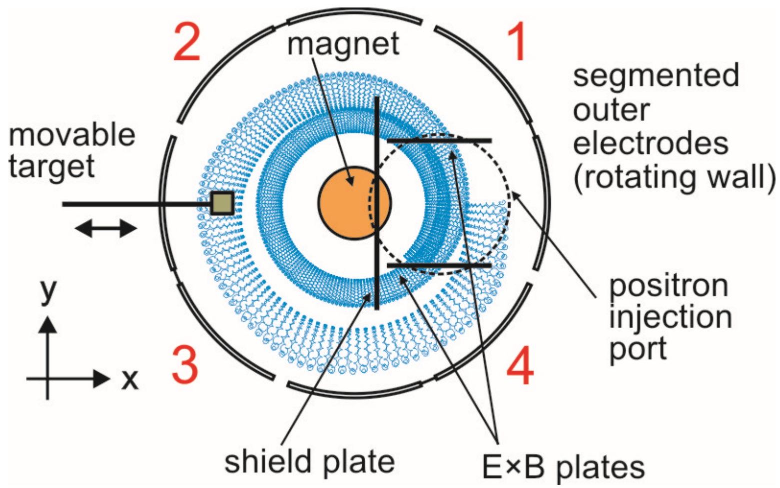


With slow positrons, precise measurements are realized with annihilation 511keV γ-rays

Motivation to use the properties of chaotic orbit in a compact levitated dipole with low energy particles

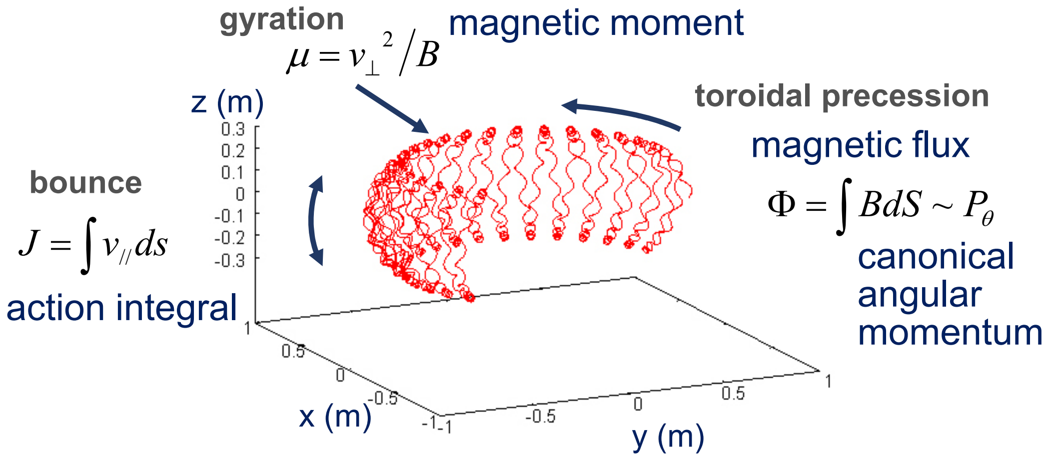
- Chaos in an axymmetric dipole field, interesting as its own right
- Toward the efficient injection scheme in a toroidal geometry:
  - For continuous injection, application of rotating wall (RW) is planned in dipole field configuration, which needs several toroidal rotations of particles
  - Chaos may realize long orbit needed for the compression phase with RW

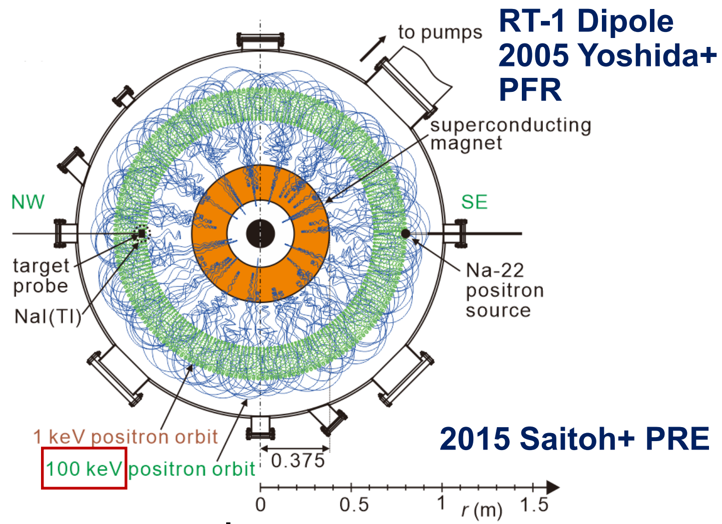




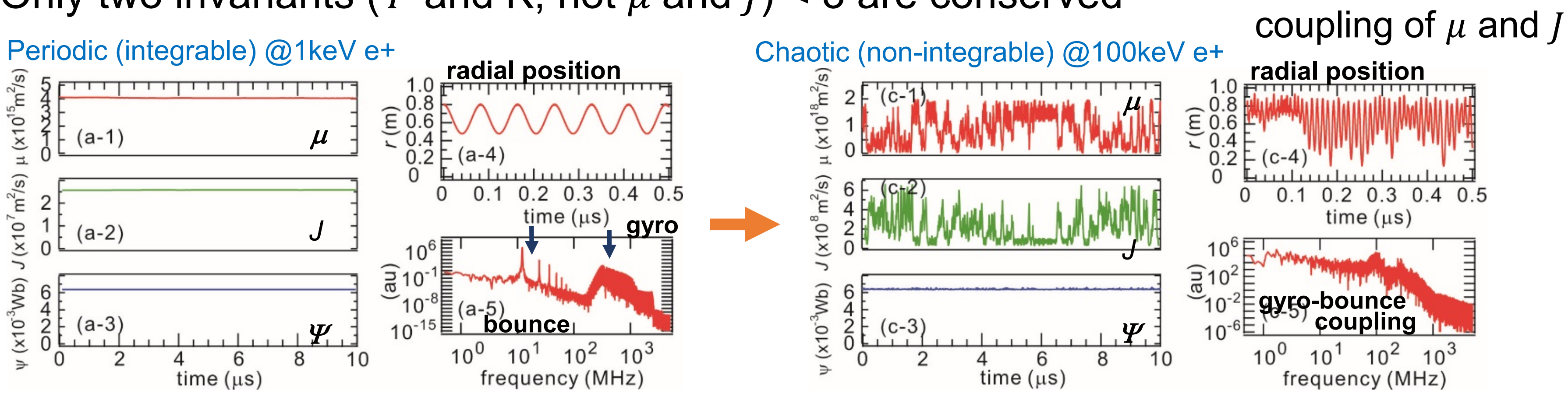
Mechanism of non-integrable chaotic motion in a dipole field: coupling of gyro and bounce motions

- Three adiabatic invariants (actions for associate periodic motions) + Energy





- Only two invariants (Ψ and K, not μ and J) < 3 are conserved



- Such chaotic motion was realized and investigated in RT-1, but **for >100keV e+s**

Chaos of low energy e+/e- in a compact levitated dipole (small B, x-point)?

Purpose of this study and definition of calculation geometry/conditions

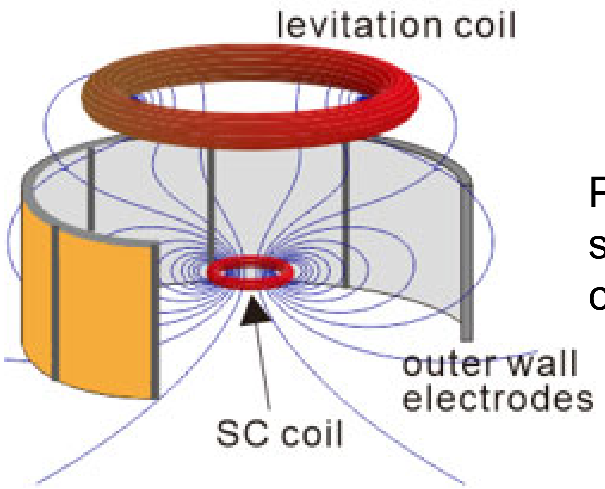
We numerically evaluate the chaos condition in the planed device parameters

Chaotic orbit exists? if so, conditions and effects to extend orbit length?

- We focus on the coupling of μ and J (not the breakdown of conservation of Ψ): resonance between gyro and bounce motions makes chaos.
- In compact levitated dipole configuration,
  - ・relatively weak field strength
  - ・magnetic null near the trap region

  may enhance the chaotic behavior.

2r=10cm, 300 turns HTS (Bi-2223) winding, up to 12kAT (40A/turn)

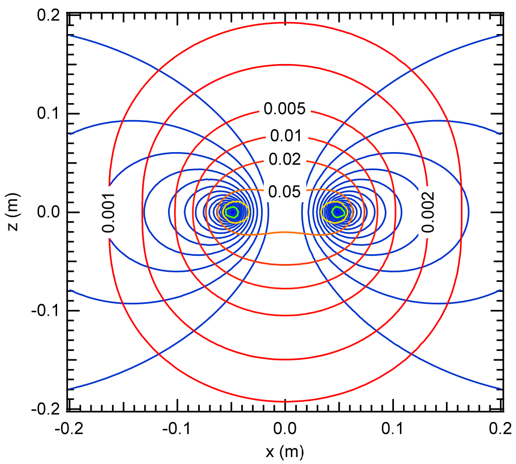


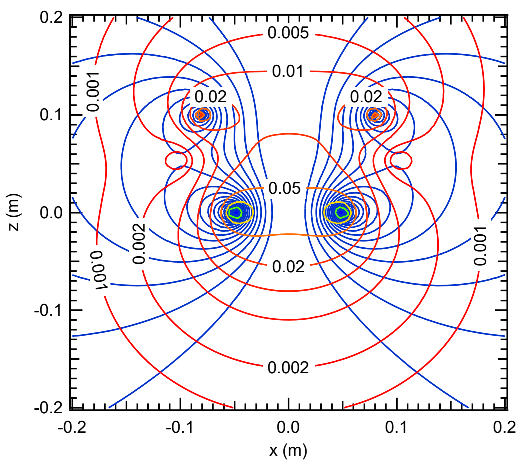
Pure dipole and separatrix configuration

Feasible with SC charging coil

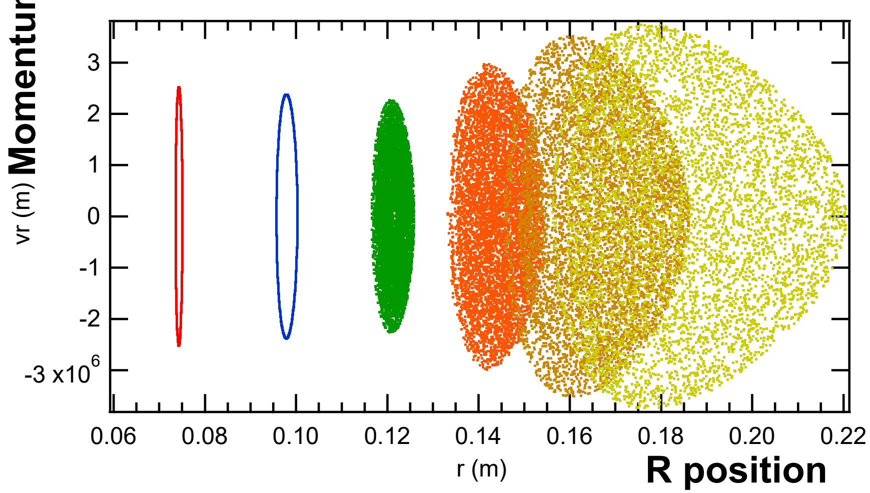
Poincaré plot of orbit shows emergence of chaos even for low energy e+/e- (K_para = K_perp = 10eV)

- **Pure dipole** config.
- **Separatrix** (dipole + levitation coil) config.

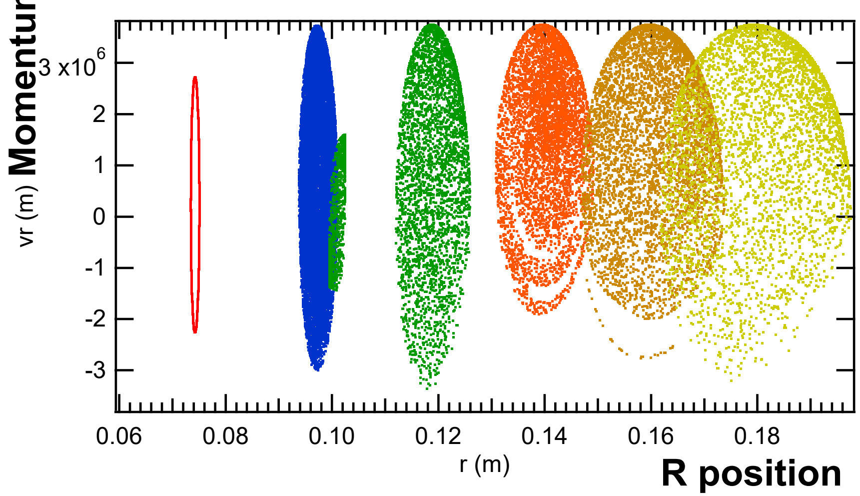




Chaos when initial R>0.12m



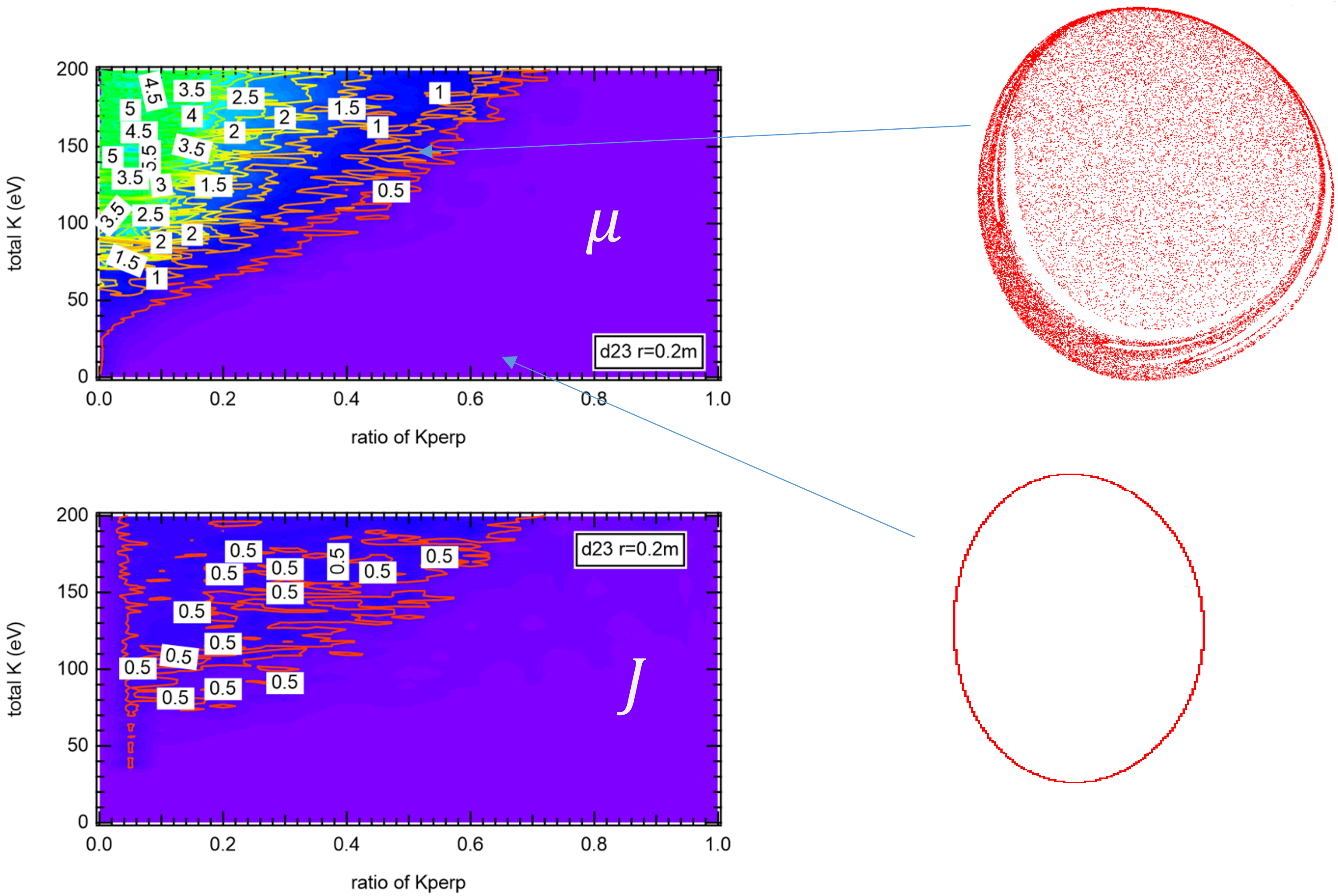
Chaos when initial R>0.10m



20eV positrons take chaotic orbit according to initial radial positions

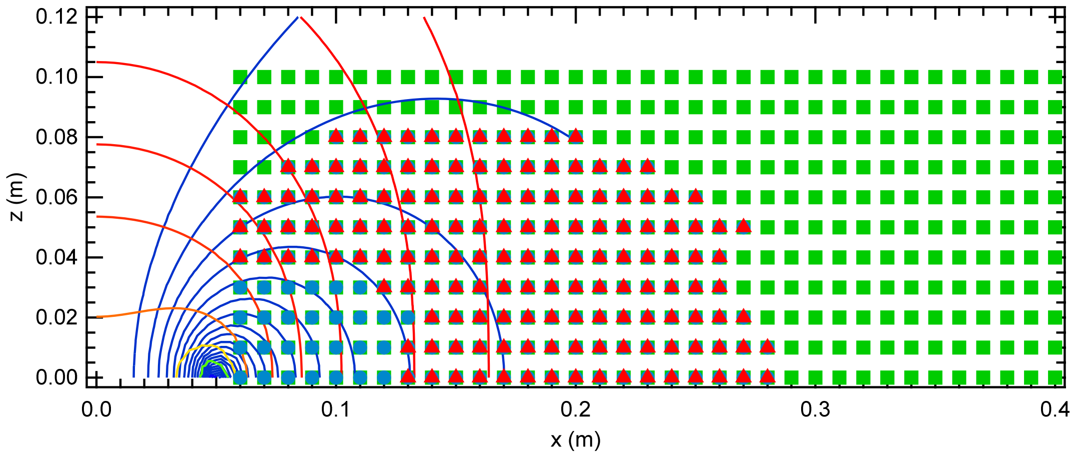
Simultaneous breakdown of μ and J conservations

- Simultaneous breakdown of μ and J, indicating the gyro and bounce coupling
- Poincaré plot shows stochastic motion when μ and J are not conserved

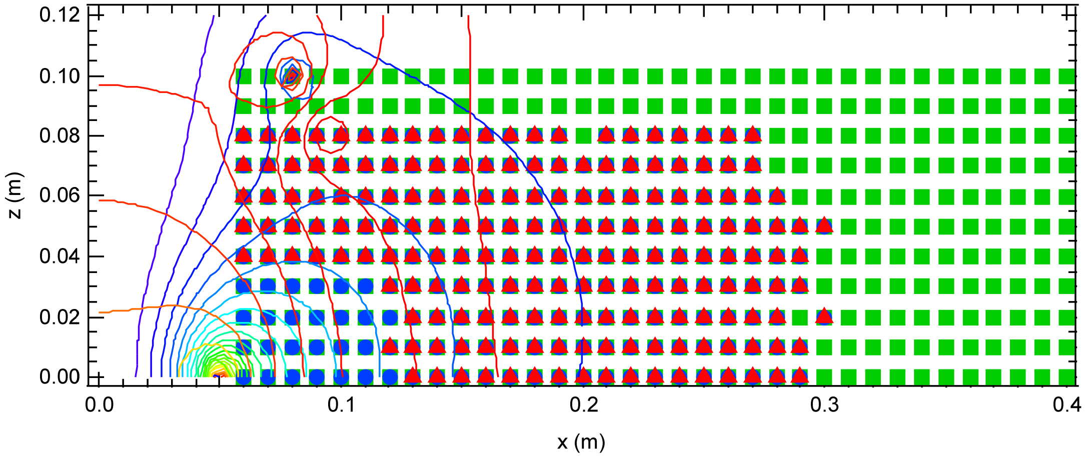


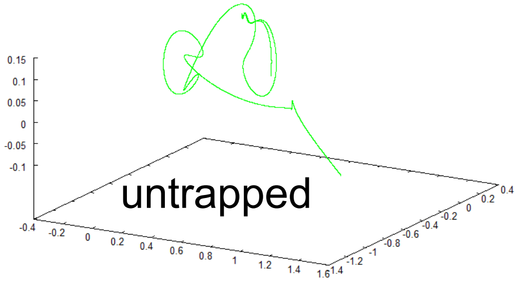
Broad "chaotic orbit region" exists between regular and untrapped orbit regions

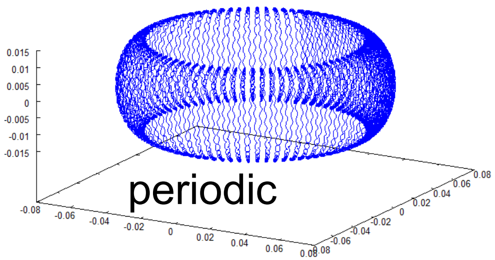
- **Pure dipole** config.

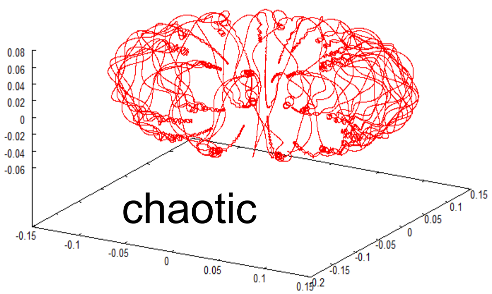


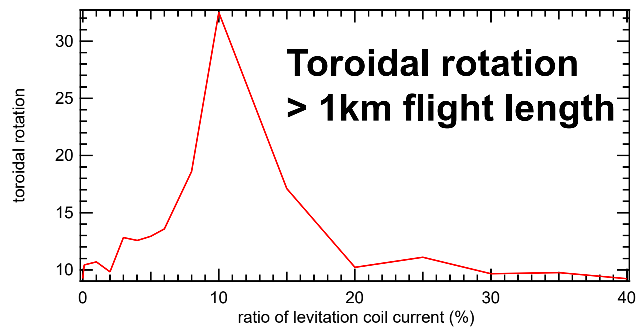
- **Separatrix** (dipole + levitation coil) config.











Summary

- We numerically traced orbit of low energy positrons in a planned compact levitated dipole to investigate conditions for chaotic orbit

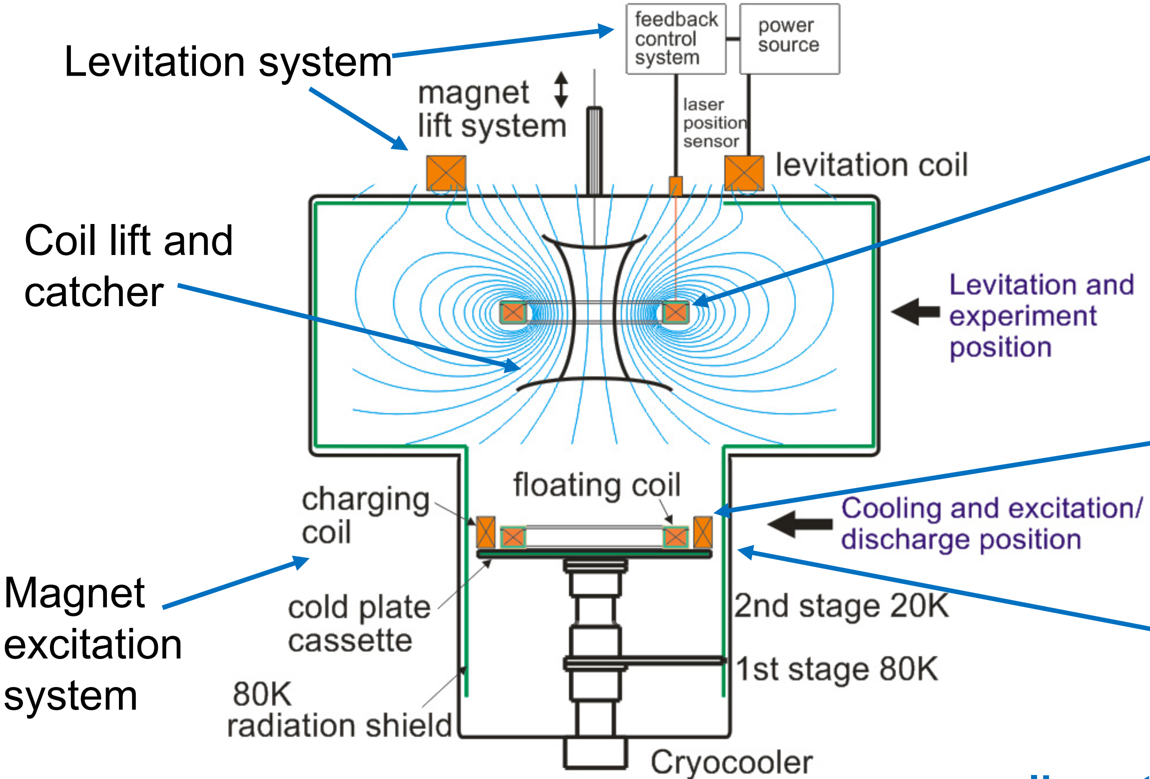
- In marked contrast to the case of RT-1 with strong magnetic field, chaotic orbit of low energy (~10 eV) do exist in this geometry

- Coupling and simultaneous breakdown of μ and J was identified as mechanism of chaos (only 2 invariants, non-integrable system)

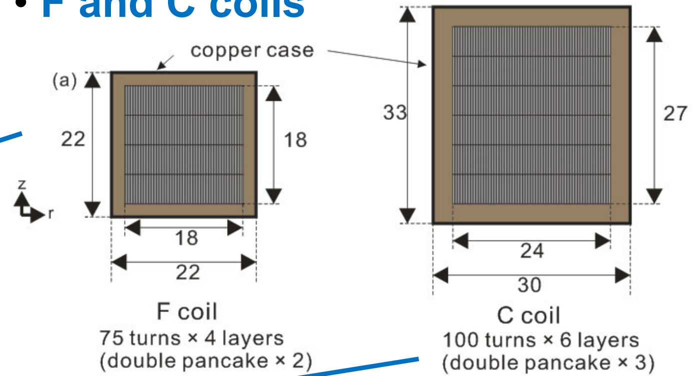
- Dipole trap has a spatially broad "chaotic orbit region“ between regular motion and untrapped region

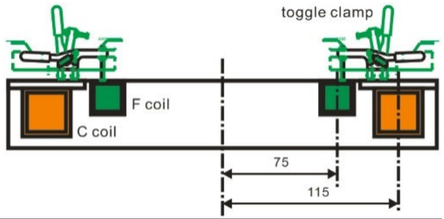
- Positrons/electrons with chaotic orbit have long orbit length (~km) even with mechanical structure of the trap system, which can be useful for the applied for rotating wall E field for orbit compression

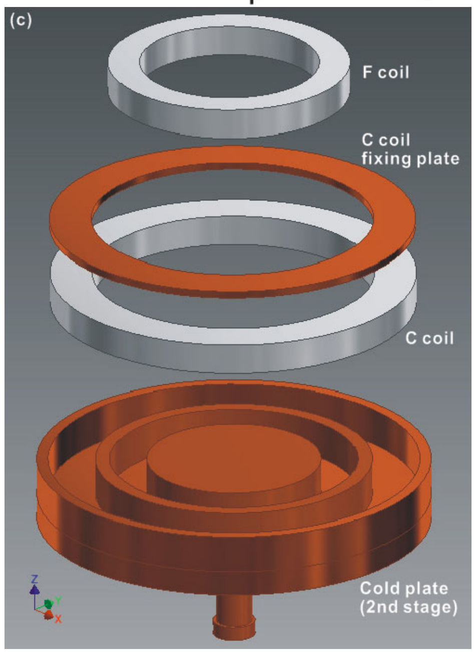
Development of a compact dipole in Japan



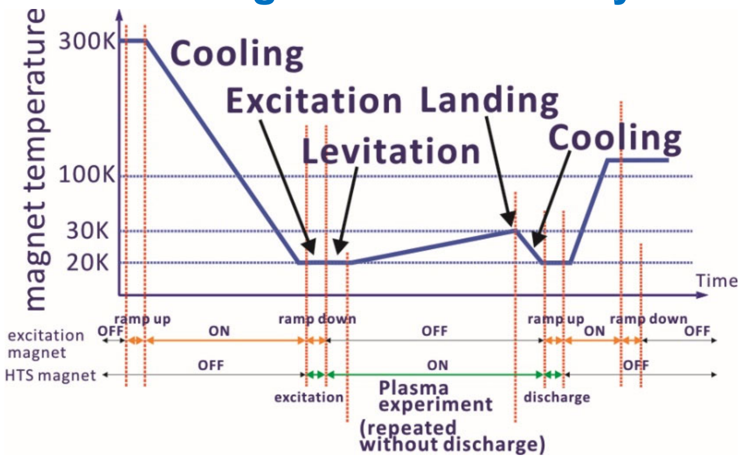
• **F and C coils**







• **coil cooling and excitation cycle**



• **cooling station for the F and C coils**

thermal contact of the F coil is realized with toggle clamps