

Novel Accelerator Concept Utilizing Cyclotron Resonance (eCRA)

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INTERNATIONAL CONFERENCE ON

ACCELERATORS FOR RESEARCH AND SUSTAINABLE DEVELOPMENT

From good practices towards socioeconomic impact



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- Possible iCRA applications
- Summary



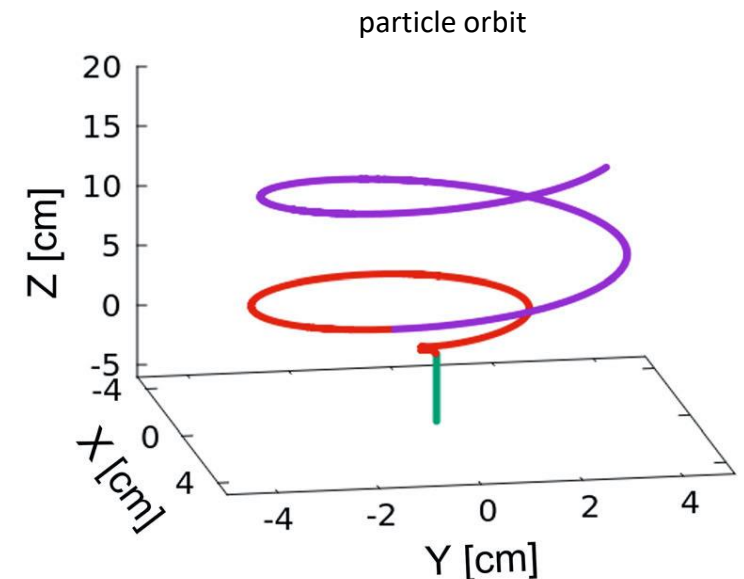
Intro

- This work is result of many years research by team of scientist of Particle Accelerator Research Foundation. Accelerator design and proof-of-principle tests currently supported by Brookhaven National Laboratory Research and Development funds.
- Any questions to specific details can be addressed to recent publication in “**Shchelkunov, Chang, Hirshfield, *Physical Review Accelerators and Beams Journal*, 25 021301 (2022)**”.



electron Cyclotron Resonance Accelerator (eCRA)

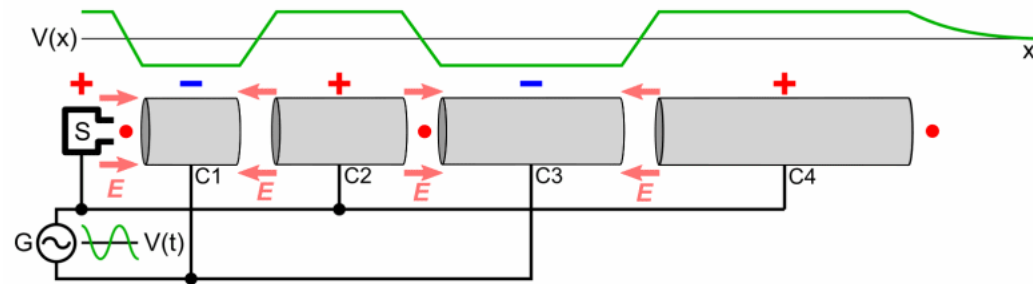
- New class of electron accelerator is based on cyclotron resonance in a TE_{111} rotating-mode microwave cavity, where particles drift along the cavity axis and gain spiraling energy from transverse electric fields.
- Acceleration mechanisms for these are based upon cyclotron resonance interactions between charged particles and RF fields in a strong external magnetic field.
- While classic cyclotron particles get energy gain in gap between dipole magnets and process multi-turn spiral orbit, in TE cavity particles getting energy gain at every step along the orbit and can reach the cavity edge in about one spin turn



Electron in $B_z=0.4$ T; $E_r=40$ MV/m

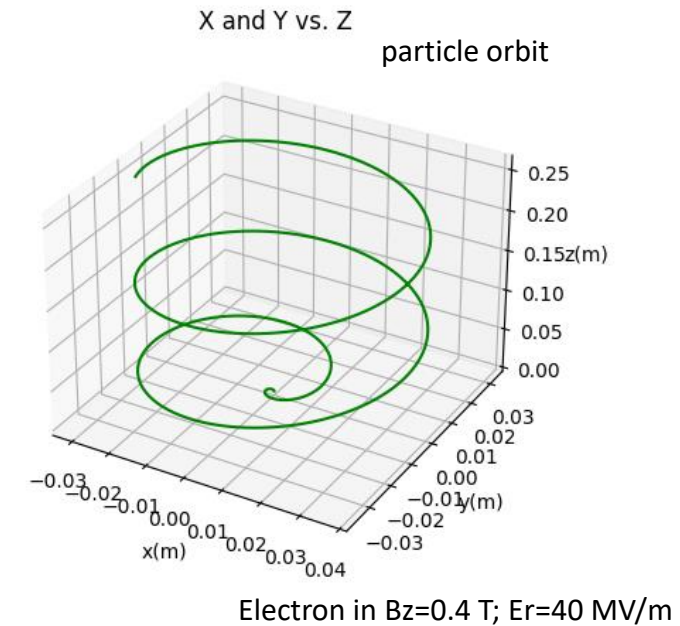
PHYS. REV. ACCEL. BEAMS 25, 021301 (2022)

Difference of eCRA and classic particle accelerator



In classic linear particle accelerator particles moving in straight line trajectory riding RF wave in TM cavities

In eCRA particles experience rapid acceleration near cyclotron resonance in rotating RF field of TE_{111} cavity immersed in external axial magnet field



eCRA advantages

- Compact design
- Continuous not bunched beam
- High current beams can be accelerated to multi-MeV levels with average power of 100 kW with 80% efficiency

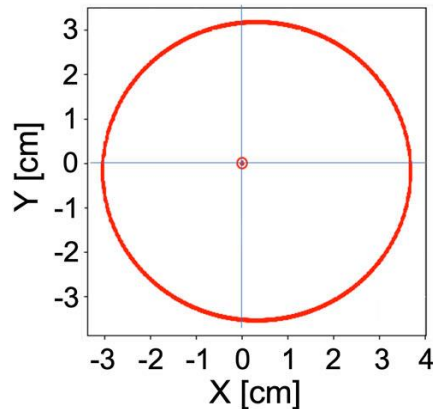


Possible eCRA limits

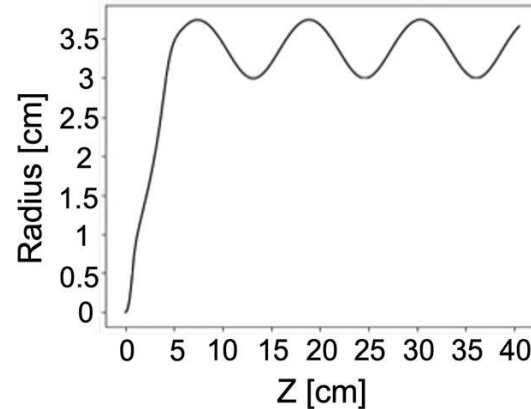
- Power limits as beam loading for high current continuous beam need to be studied
- Heat load at beam dump at cavity end may be a problem for some eCRA applications



Simulations

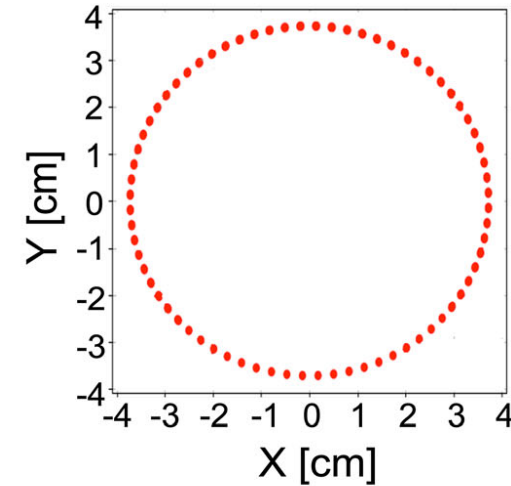


(a)



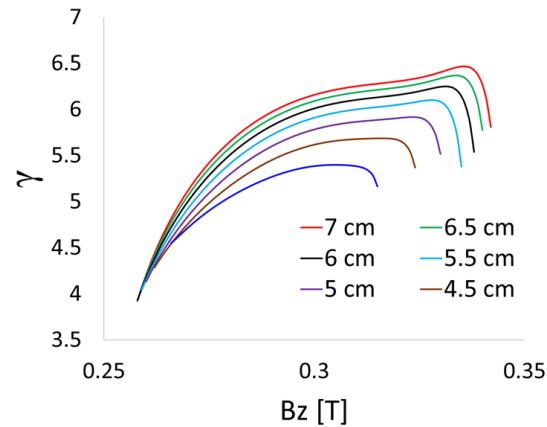
(b)

(a) Projection on a plane transverse to the cavity axis over one or more rf periods of the eccentric helical orbit of an accelerated particle. Note the 0.35 cm offset of this helix's axis from (0,0). (b) Plot of the radial coordinate of a particle along z showing the undulation from its initial radial kick that causes the offset of eccentric helical orbits.

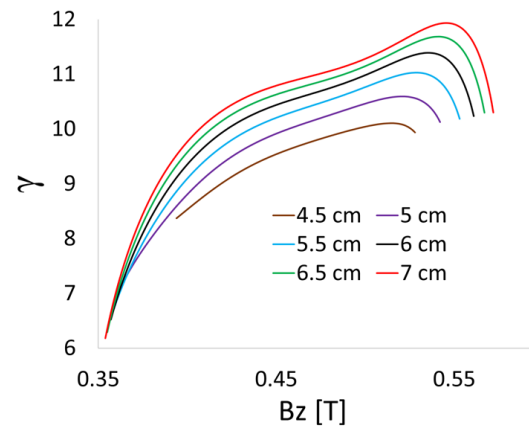


Superposition over a full cycle of the loci of orbit intersections where particles intersect a target beyond the cavity. This shows how an eCRA beam is centered on (0,0), how it would scan and deposit its energy uniformly around a circle on a target, and how it remains unbunched.

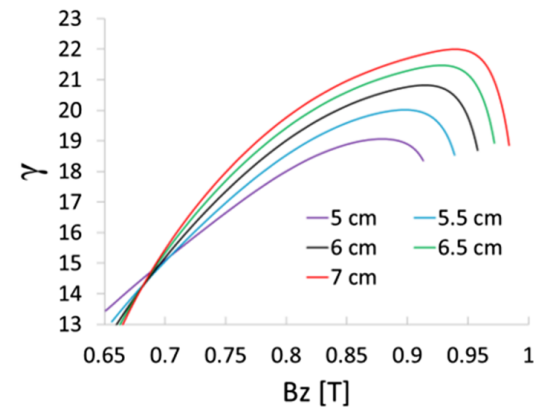
Simulations (cont.)



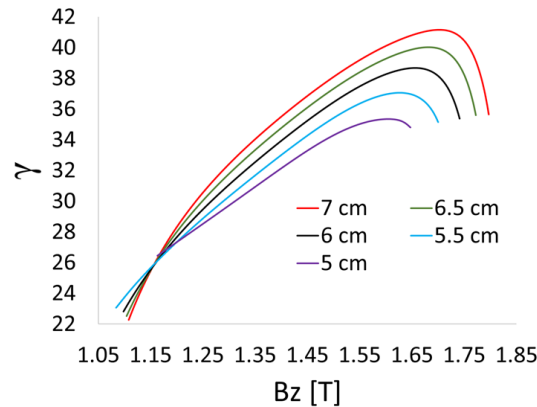
(a)



(b)



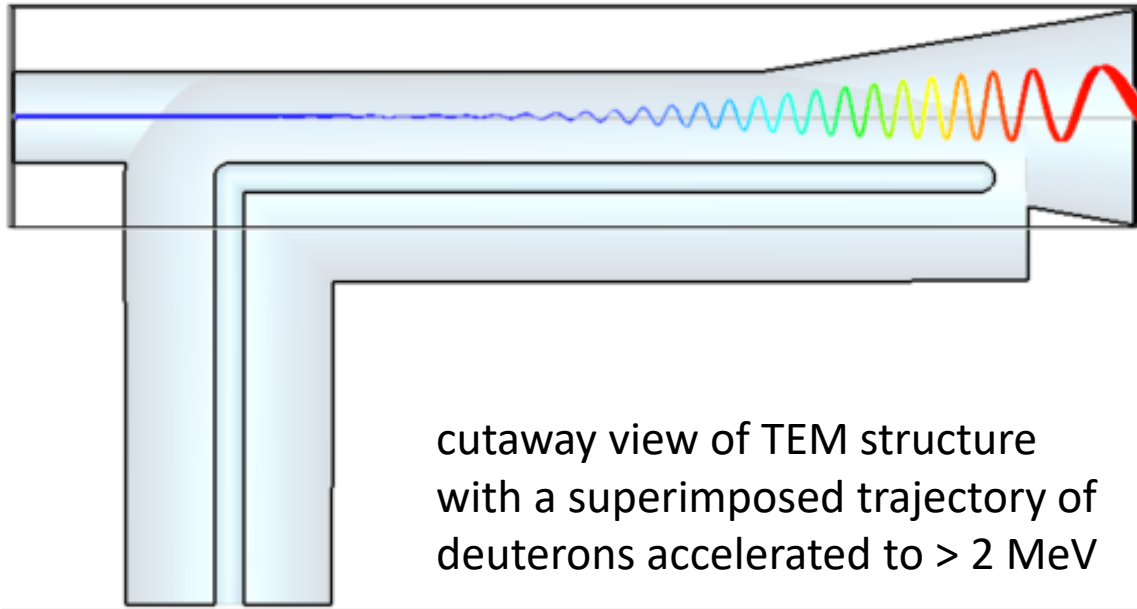
(c)



(d)

Behavior of final values of γ vs B_0 as electrons exit cavities of various radii, with curves labeled according to the cavity radius R in cm. (a) $E_w = 20$ MV/m (b) $E_w = 50$ MV/m (c) $E_w = 100$ MV/m (d) $E_w = 200$ MV/m. Energies of accelerated electrons in these examples are between about 2 and 20 MeV.

ion Cyclotron Auto-Resonance Accelerator *i*CARA



Typical layout of CARA, where power from an RF source is coupled into a hollow waveguide or resonant cavity permeated by a profiled DC axial magnetic field, and a charged particle source injects a continuous (un-bunched) beam into the structure. At resonance, continuous acceleration of the gyrating beam occurs. The beam then spreads adiabatically in the diverging magnetic field and self-scans on a circle as it moves to and beyond the exit of accelerating structure

Possible eCRA applications

Applications for the (up to) 10-MeV electrons with average beam powers up to one megawatt include:

- environmental remediation of a range of pollutants
- sterilization of medical instruments and supplies
- production of high fluxes of energetic photons (gamma-rays) and neutrons
- novel strong sources of THz radiation.



Possible iCARA applications

- Radioisotope production that may have order-of-magnitude increase by iCARA
- Medium energy alpha beams (several tens of MeV) also have great potential for medical applications
- iCARA as a Driver for a Neutron Source. Low-energy protons or deuterons accelerated using iCARA can serve as drivers for copious neutron production via reactions on lithium
- The beam scans through a full circle on a target in one RF period, which can lower the instantaneous and average heat deposition per unit scanning path, as compared with conventional much slower scanning (restering) that can deposit large power beams with attendant localized heating.



Summary

- Exact numerical solutions for the single particle equations of motion have revealed conditions for strong acceleration near cyclotron resonance for electrons injected into a TE₁₁₁-rotating-mode cylindrical cavity immersed in a strong axial magnetic field
- High current beams with accompanying heavy beam loading are shown to experience acceleration in eCRA to multi-MeV levels for beams with average powers of hundreds of kW and efficiencies that exceed 80%
- eCRA and iCRA are particle acceleration mechanisms that can be used in compact novel accelerators in various applications: high flux gamma-source, sterilization of medical instruments and supplies, environment remediation of a range of pollutants, radioisotope production



Thank you!!

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