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#363 PIP: a compact recirculating accelerator for medical isotopes

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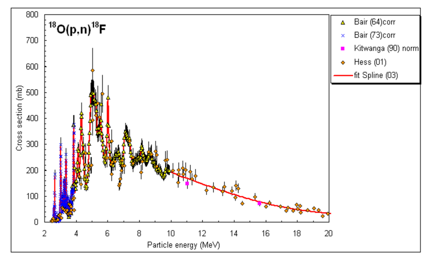
A small low-energy nsFFAG concept that uses a re-cycling beam and internal target to produce medical isotopes. It can also produce neutrons for security scanning and other purposes

Medical isotopes – PET and SPECT

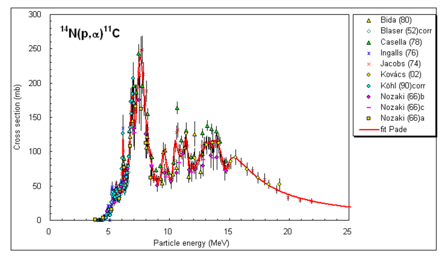
For making medical isotopes, for imaging or for treatment, low energy accelerators have advantages over high energy accelerators, and reactors. Isotopes can be produced locally, on demand, rather than delivered from some remote distribution centre.

Medical isotope production cross sections have respectably high peaks, but they are narrow.

Taken from the IAEA-NDS website



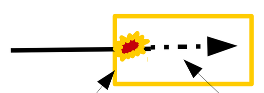
PET isotope ^{18}F used for DFG monitoring



PET isotope ^{11}C with many potential uses

Targets: thick versus thin.

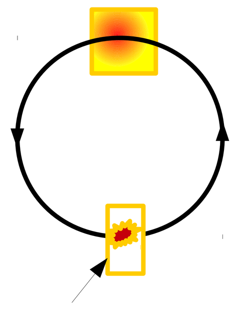
Particles lose energy as they travel through the target material. Particles which do not interact at the peak energy just slow down and stop.



Can interact

Can't interact – energy too low

In a thin target particles that do not interact can be sent round for another try



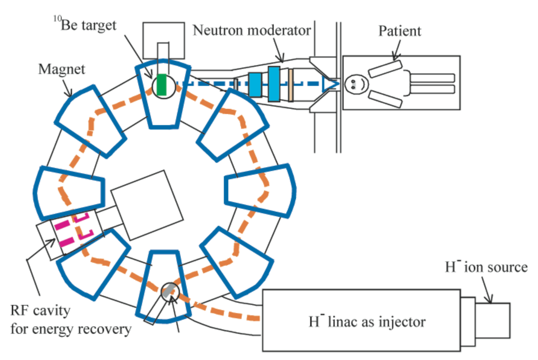
Can interact

Particles lose energy in the target and regain it from the RF system.
The bunch is also scattered by the target, increasing the emittance. The RF system decreases that Emittance ('ionisation cooling').
Nevertheless the emittance can become large, and the wide acceptance of an FFAG is needed.

ERIT shows the way

Concept implemented at ERIT
(Energy Recovery with Internal Target) at KURRI, Japan.
9 MeV FFAG ring for BNCT neutron production

Protons circulate ~1000 turns



Schematic from K Okabe, image from Y Mori

The difference

ERIT is a storage ring with separate accelerator
PIP combines the two

PIP-4

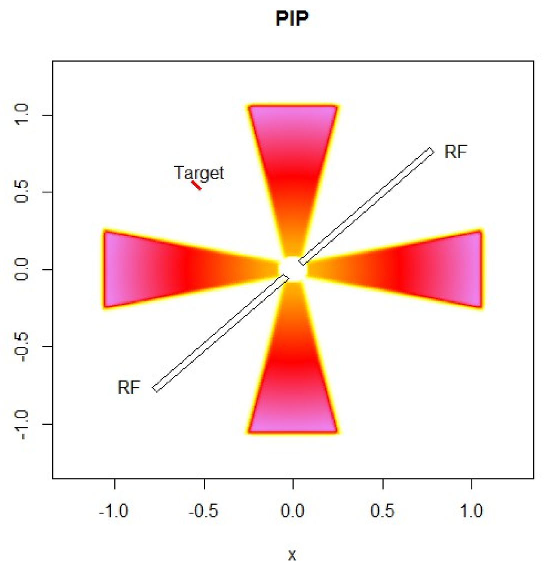
PIP is a 1m radius nsFFAG, from a field map produced by Carol Johnstone. The field from 4 sector magnets increases with radius. RF is provided by two cavities, and a target is in one of the straight sections.

The energy of the interaction can be adjusted by placing the target in different locations.

The version of PIP we have studied is designed to accelerate protons from 50 keV to 4 MeV. It is one member (the smallest) of a class of designs with the same magnet and RF configuration.

Such a machine would be small and cheap enough for every hospital to have one, producing isotopes on demand.

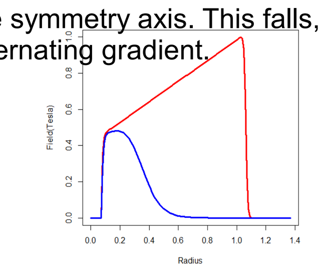
A similar accelerator/target design will produce copious neutrons from a thin Be target.



Is this a cyclotron or an nsFFAG?

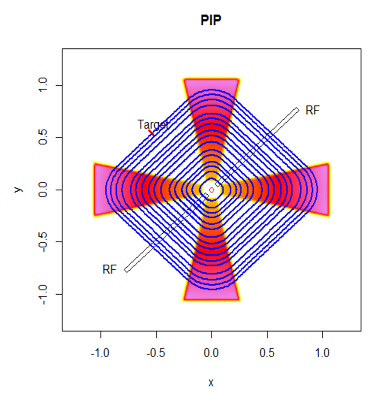
At first sight this looks like a cyclotron. There are no obvious counterbends, as you expect in an FFAG.
But this is deceptive. The radial field variation is enormous. The red curve in the figure shows how the magnetic field at the centre of the magnet increases from 0.5T to 1T from the inner to the outer radius. The field in sector cyclotrons does vary, but only by a few percent. This high gradient is characteristic of an FFAG.

The blue curve shows the field variation along the radius 30 mrad off the symmetry axis. This falls, due to edge scalloping, providing the alternating gradient.

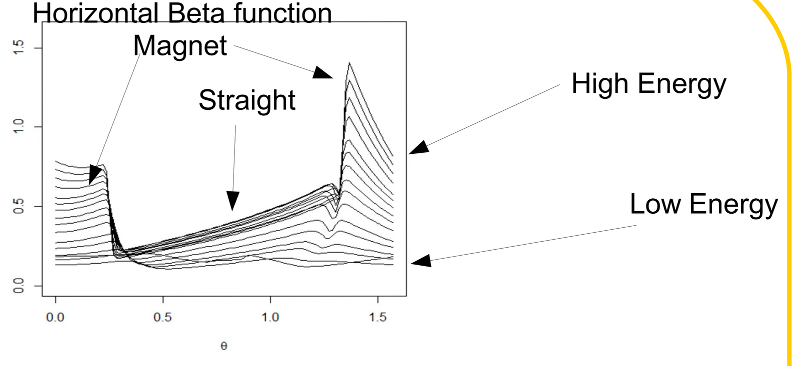


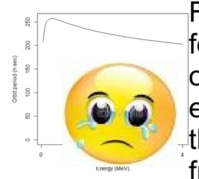
These alternating gradients provide strong focussing, making this, we would argue, an FFAG.

From this field map one can construct the reference orbits for energies in the range 50 keV-4 MeV.

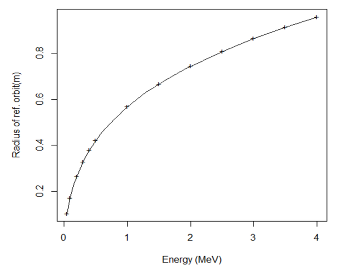


The figure shows the radius as a function of energy (line) in our simple simulation. The crosses are a cross-check with calculations done by Suzy Sheehy, using the full OPAL code of Andreas Adelmann The excellent agreement validates our program.

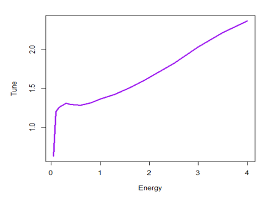




From these orbits one can find the time for each orbit, and thus the isochronicity of the lattice. The period varies with energy: although only by a small amount this is enough to prohibit CW fixed-frequency operation. A further design iteration on the fieldmap will be needed for this.

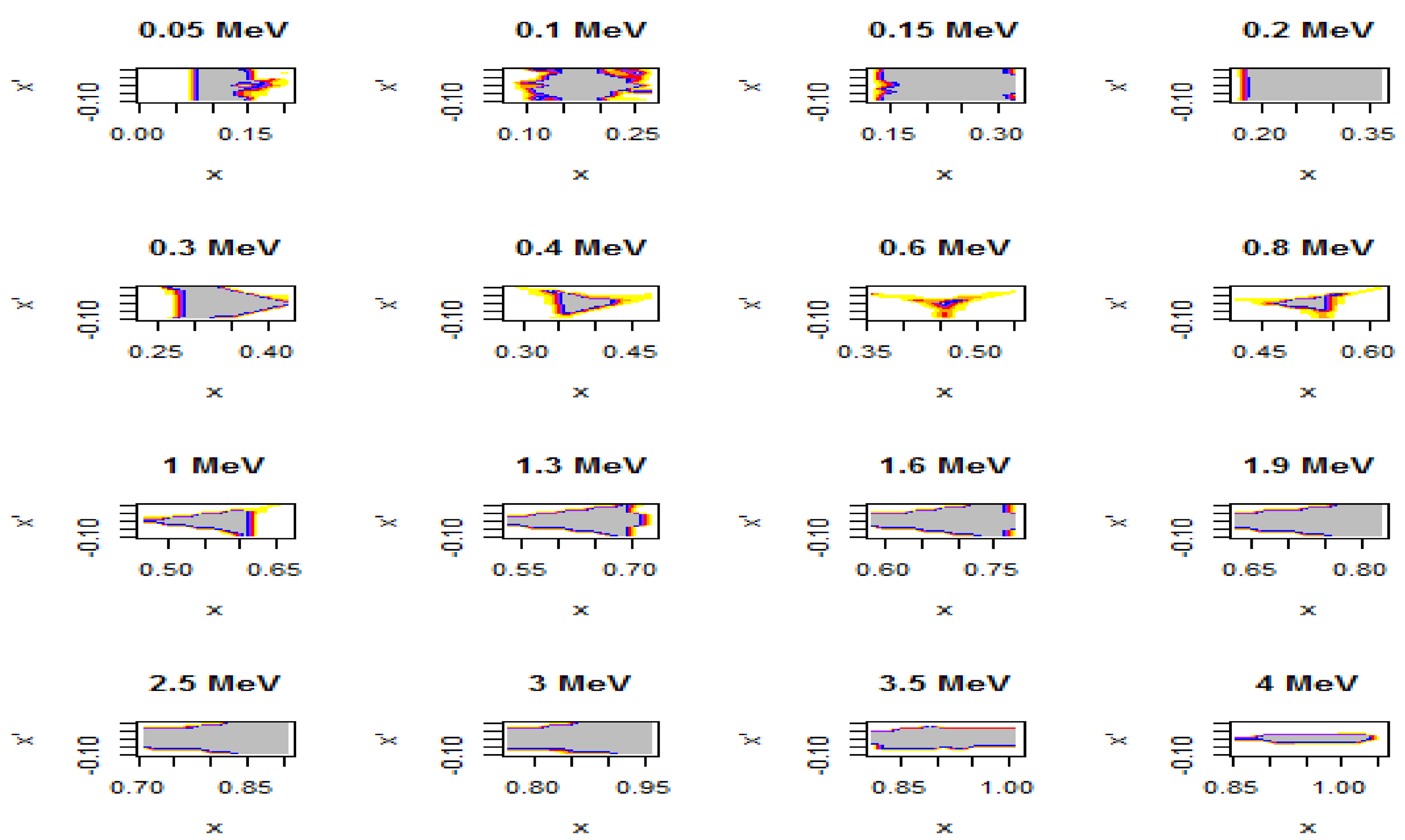


The tune does vary with energy, as expected, and passes through the dangerous ν=2 resonance.
Is this fatal? Not necessarily, as EMMA has shown.



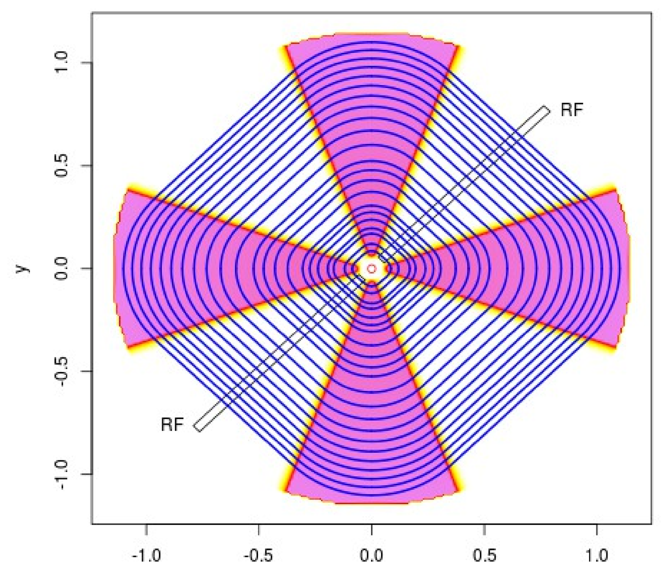
Acceptance

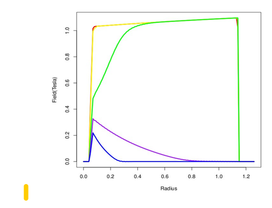
Survival studied at many energies - the grey areas show phase space where particles survive 250 turns (i.e. forever)
These are ENORMOUS: scale is 20 cm by 200 mrad Interesting structures – need study and understanding



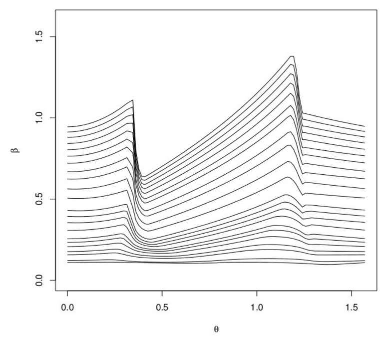
PIP-14

A larger machine on the same basic principle with a greater radius (1.2 m) is designed to reach proton energies of 14 MeV. This brings many additional uses, including ^{99m}Tc production.

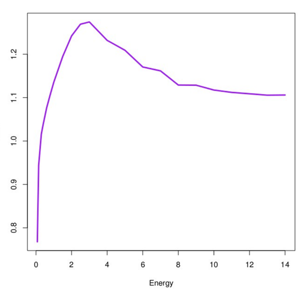


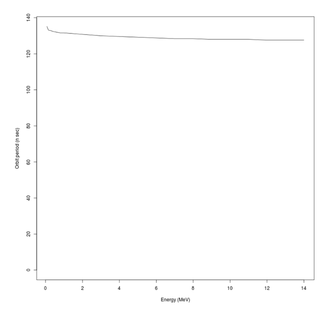


At first sight similar to PIP-4, PIP-14 orbits have a much higher field/no-field ratio. The radial dependence B(r) is much smaller. (Field profiles at 0,0.1 0.2, 0.3 and 0.4 radians are shown)



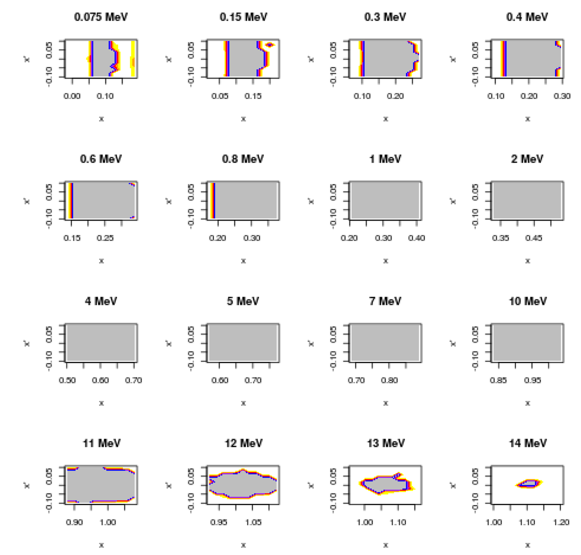
The β_H function shows the drastic effects of the sharp edges. The tune is fairly flat.





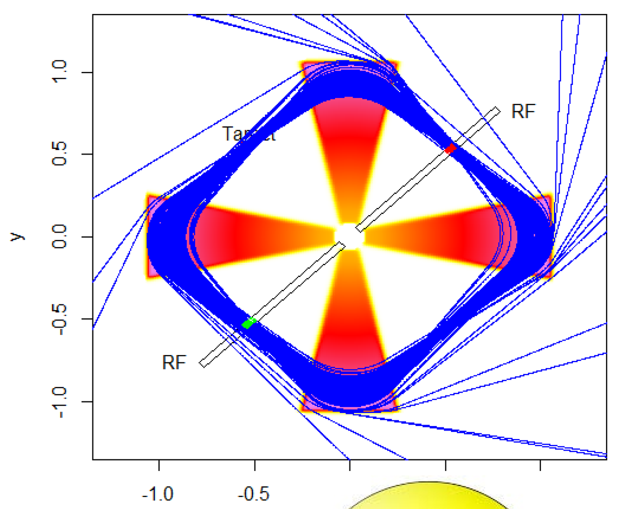
The isochronicity(left) is a lot better.

The acceptance is large, and shows no mid-range constriction.



Simulation of energy loss and scattering

The beam can be guided back to hit the target many times, recovering energy and emittance from the RF



Conclusion

Despite their similar appearance, PIP-14 and PIP-4 have significant differences in behaviour. This is hopeful as it tells us there is a lot of scope for optimisation.

More studies (including OPAL and COSY-infinity) are under way

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