Science & Technology Facilities Council

Small scale FFAG test facility

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Background
RAL

Initial goal of Front End Test Stand (FETS) project at RAL is now nearly achieved.

What is FETS?

(From A. Letchford's slide at PASI 2012)

The key components of FETS are:

- *High intensity, high duty factor, H- ion source.*
- *Magnetic Low Energy Beam Transport (LEBT)*
- *324 MHz 4-vane Radio Freq Quad (RFQ)*
- *Medium Energy Beam Transport (MEBT)*
- *Very high speed beam chopper*
- *Comprehensive diagnostics*

What is the aim?

(From A. Letchford's slide at PASI 2012)

…

The Front End Test Stand (FETS) aims to demonstrate key technologies for the front end of the next generation of high power pulsed proton accelerators. FETS is the only dedicated high power proton accelerator hardware R&D in the UK.

…

H- ion source
LEBT
RFQ 3 MeV
MEBT
 w/ novel Chopper

Background

RAL

Discussion started on “what next?”

— …

— *Energy booster by linac.*

— *Small ring test facility.*

— …

H- ion source
LEBT
RFQ 3 MeV
MEBT
w/ novel Chopper

The bottom line is

High quality H- beams will be available at RAL.

kinetic energy:	3 MeV
normlised emittance:	1 pi mm mrad
pulse duration:	up to 2 ms
peak current:	60 mA

Let us propose a project to use them!

Sounds similar to the beginning of ALICE/EMMA?

Possible project goals

from machine designers point of view

Task 0 5 August 2014, v0 Machida

Design decision	Study items	Remarks
Transverse optics/dynamics		
Scaling or nonscaling	Resonace crossing	Possibly no crossing is preferable.
Linear or nonlinear		
Conventional, pumplet, SOC, etc		
Horizontal, vertical or both	Vertical orbit excursion	
	Separated orbit cyclotron	
Injection	Phase space painting	Might be difficult at 3 MeV (foil scattering, large beam).
	CW injection	
Extraction	Slow extraction	Need tune control.
	1 kHz extraction	
	H- stripping extraction	
	CW extraction	
Longitudinal optics/dynamics		
CW or pulsed	CW acceleration	
	Harmonic number jump	
	Constant bucket acceleration	RF voltage could be large.
	Serpentine channel acceleration	Not much application later.
	ASTOR concept by Joho (1973)	
Collective effects		
	Space charge	
	Coherent instability	

Possible proposals

1. High intensity FFAG ring study with 3 MeV beams

   Large space charge effects due to low energy.

   Machine will be like KURRI/Booster (2.5 - 25 MeV).

   Similar study is underway at KURRI/MR.

2. Test bench of a novel FFAG

   Proof of principle of any kind.

   Energy range is just for isotope production.

My proposal

goals

Demonstration of ultimate fixed field accelerator

Can be cyclotron, can be FFAG or can be both.

Capable to operate with fixed frequency, fixed tune and fixed field.

Demonstrate methodology of construction/operation of future fixed field accelerators.

Depend on multipoles from design to operation.

Flexibility to adjust injection/extraction region with the same knobs (normal and skew multipoles).

Allow vertical orbit excursion as well.

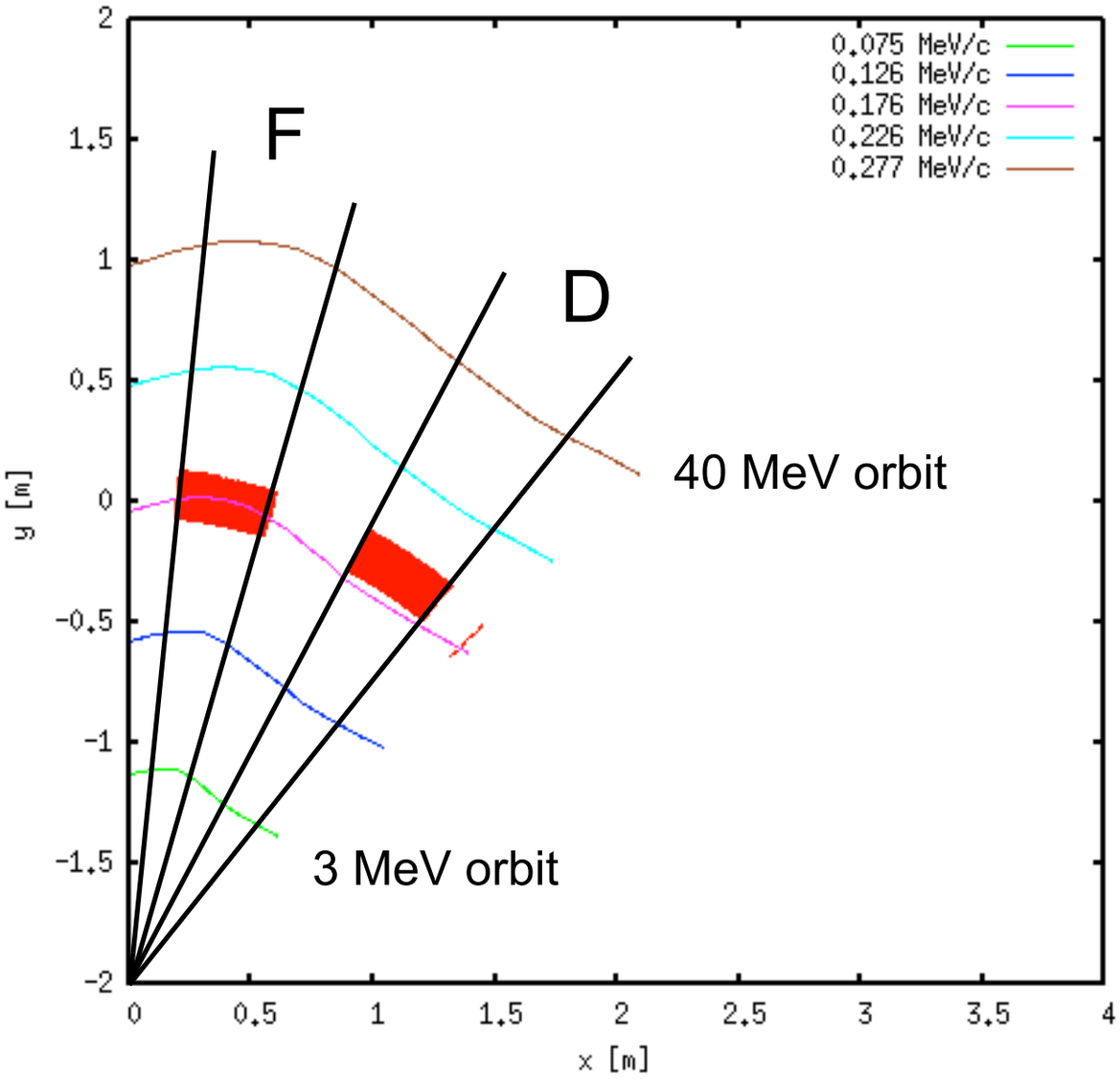
My proposal

from slides on Wednesday

Toy model as a start

8 cell lattice

Simple FODO lattice with 8 cell per ring



energy: 3 - 40 MeV

field: 1.5 T max

packing factor: 0.5

Start from scaling FFAG optics.

Then control individual multipoles.
(as we did for PAMELA.)

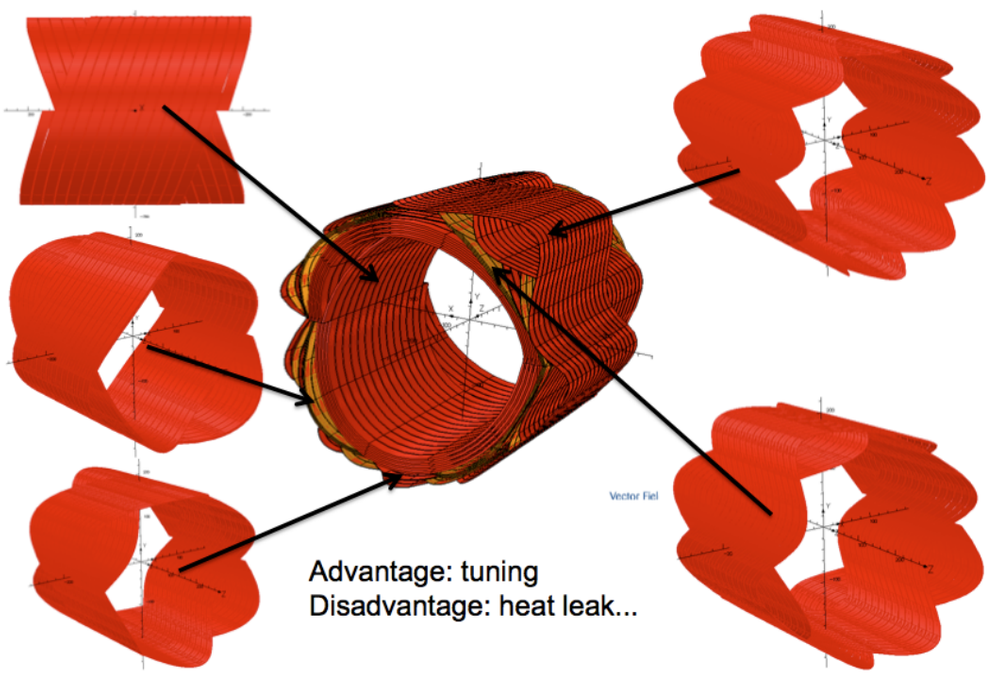
Magnetic field profile

multipole expansion

Any magnetic field profile can be reconstructed completely by multipoles.

In practice, the first few normal multipoles are enough to shape field profile which satisfies beam dynamics.

PAMELA magnet is an example.



$$B_z = B_{z0}\left(\frac{r_0 + r}{r0}\right)^k$$
$$= B_{z0}\left(1 + \sum_{n=1} \frac{1}{n!} \frac{k(k-1)\cdots(k-n+1)}{{r_0}^n} r^n\right). \quad (3)$$

dipole, quadrupole, sextupole, decapole, dodecapole

by Holger Witte

Other possible knobs

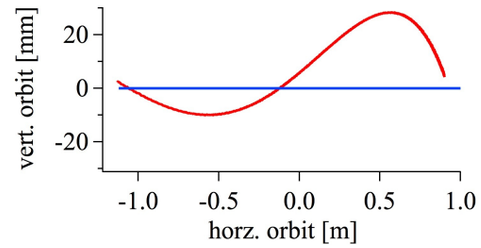
use of skew

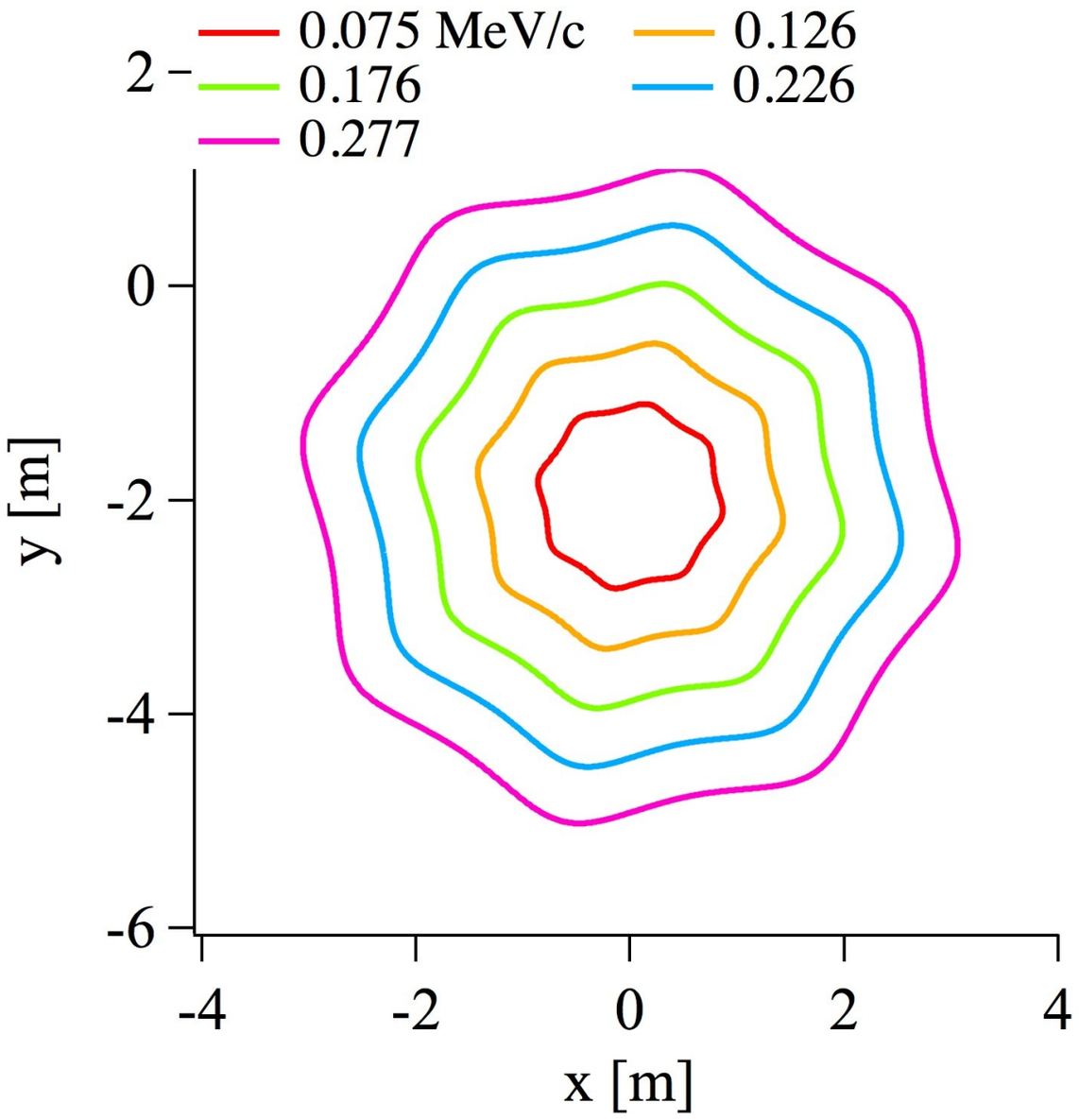
Other knobs we did not use at the time of PAMELA study is skew multipoles.

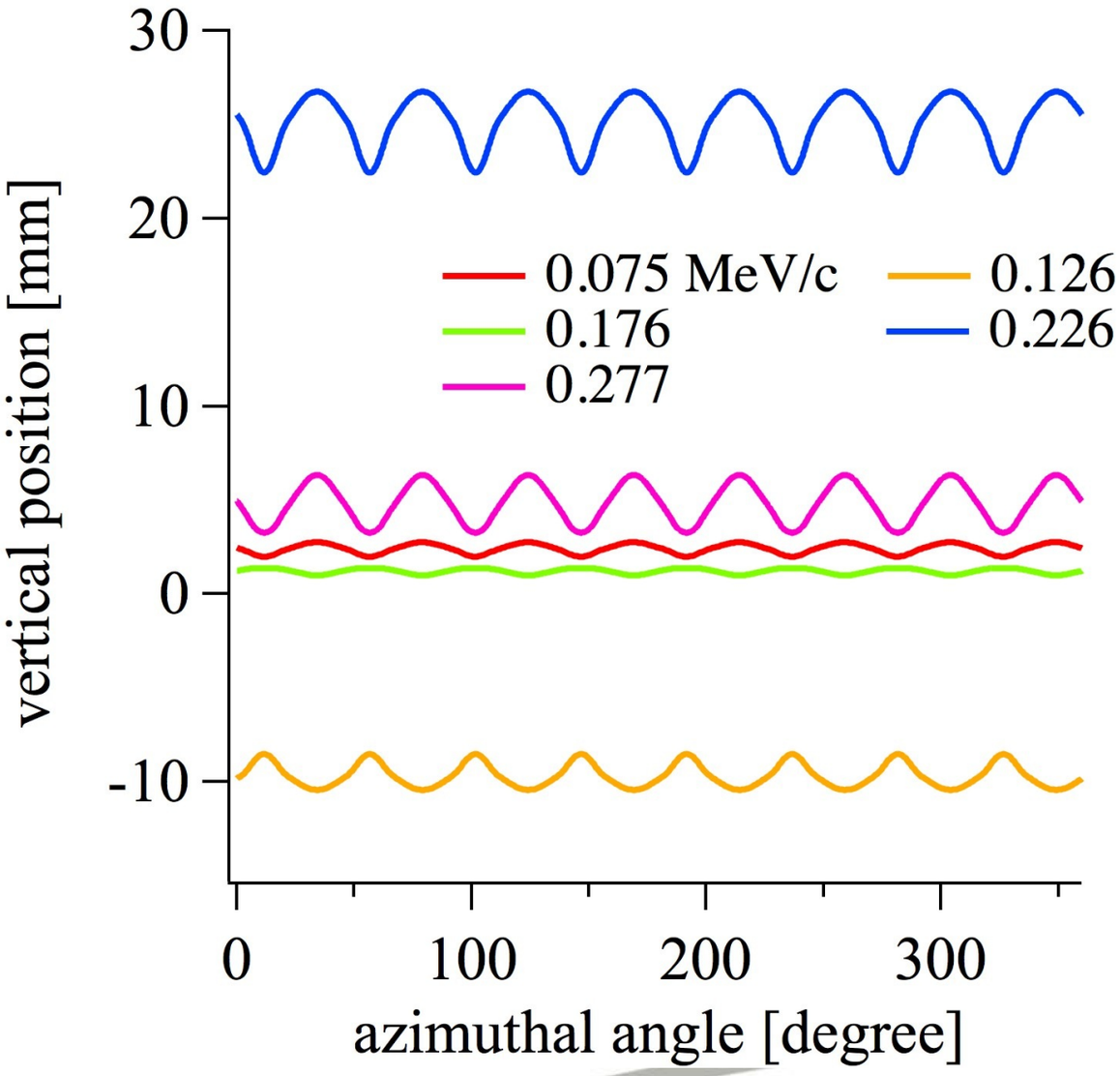
This is also the key ingredient of VFFAG and 3D cyclotron by S. Brooks.

Orbit excursion in vertical as well as in horizontal

Closed orbit







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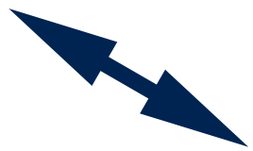
With normal and skew multipoles

cyclotron, FFAGs or both

We can minimise the spread of tune and revolution time at the same time with skew multipoles.

cyclotron mode
(fixed frequency)

FFAG mode
(fixed tune)



“complete isochronism" mode
(fixed frequency and fixed tune with fixed field)

named by J. Teichmann (1962)

The key issue

I think

Demonstration of effective knobs and their use in fixed field accelerators (cyclotrons and FFAGs) is the key issue for those accelerators to be adapted for wider usage/applications (beyond a machine for its own research).

Find out the right number and the right place of knobs.

Identify which knobs should be kept available for the daily operation and which knobs should be fixed after initial tuning.

Demonstrate possibility to have long straight sections.

Edge focusing can be used in the design stage as long as there is correction scheme on the operation stage.

Immediate impact

Prototype of neutron source driver
e.g. 0.5 to 10+ MW ISIS upgrade

High intensity FFAG

Compact application machine
e.g. Isotope ^{99}Tc production (40 MeV, 5 mA, D)

Should be industrialised following this project

Prototype of medical machine

Operation friendly machine with spot scanning