



Future R&D

**- Small scale ring and
possible KURRI/Kyushu experiments -**

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Small scale FFAG at FETS

FETS ring at RAL

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*

Introduction

Considerable progress has already been made on the ground at RAL.
However there is much still to do ...



FETS ring at RAL

The bottom line is

High quality H- beams will be available at RAL.

kinetic energy:	3 MeV
normalised 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?

FETS ring at RAL

1. Test bench of a novel FFAG

Proof of principle of any kind (VFFAG, DF-Spiral, etc).

2. High intensity FFAG ring study with 3 MeV beams

Large space charge effects due to low energy.

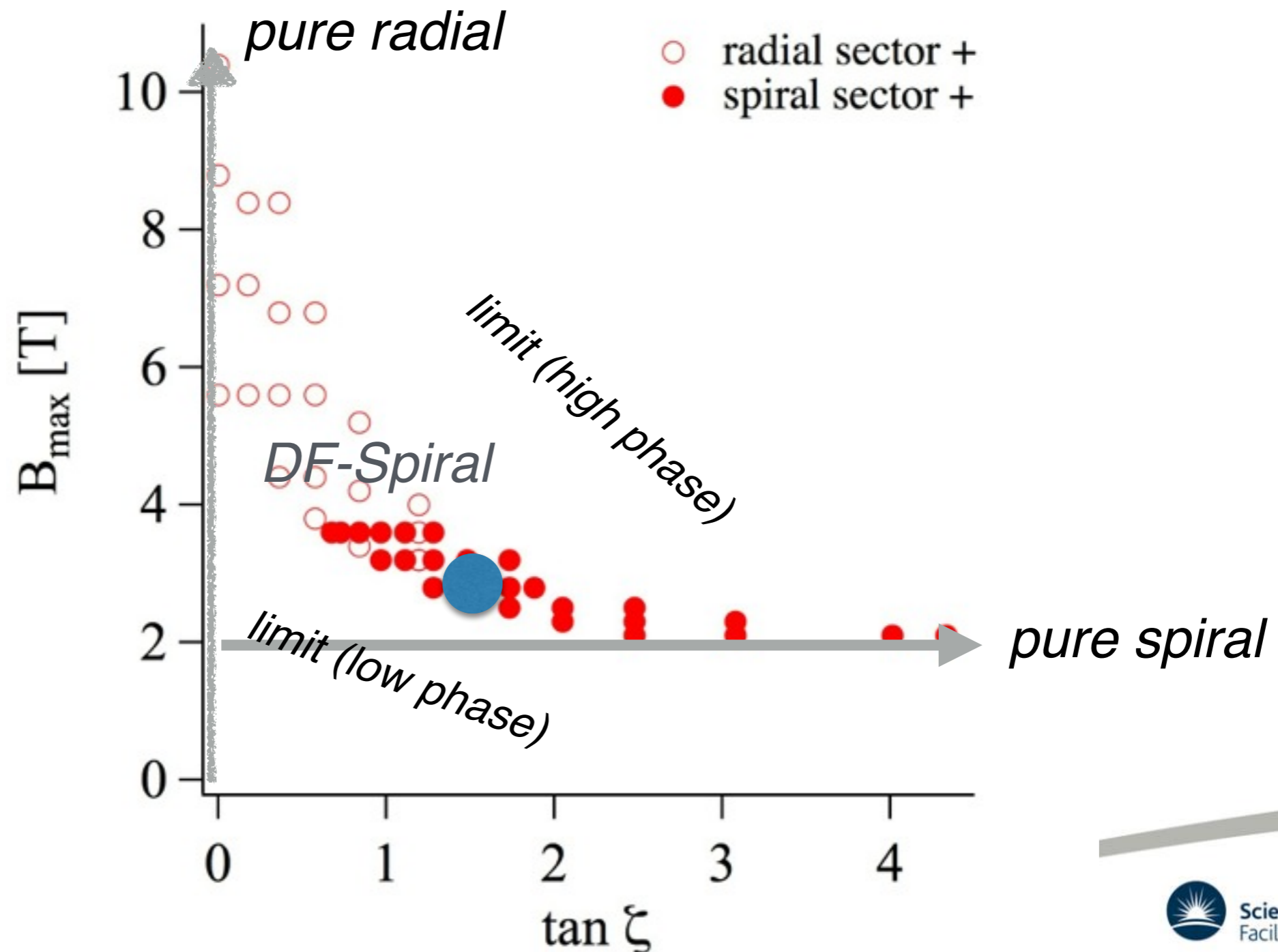
3. Also

Energy range is just for isotope production.

Parameter search

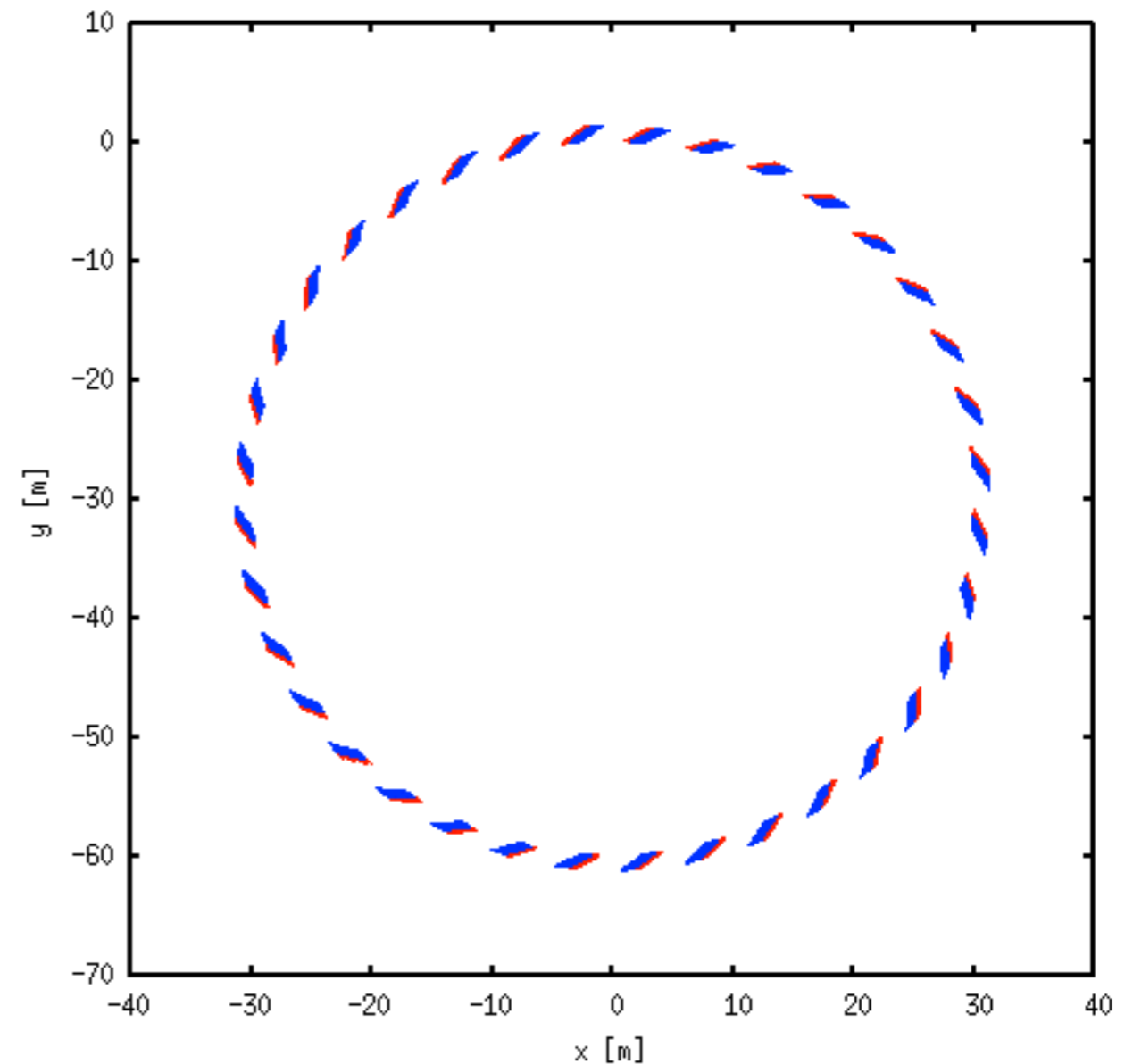
Parameter search

Practically, the best parameter is obtained with the balance between B_{max} field and spiral angle.



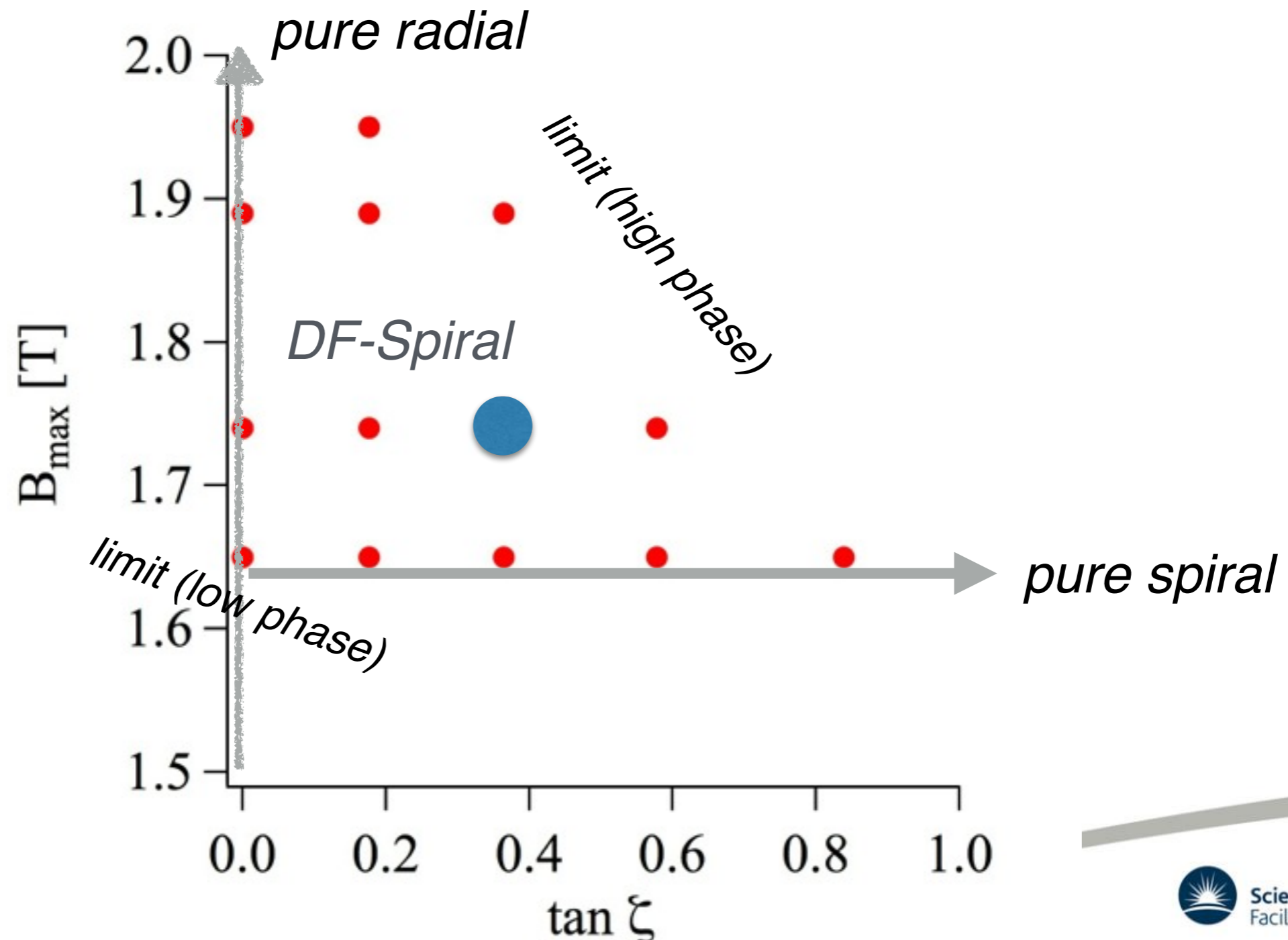
Parameter search

Type	DF-Spiral
Kinetic energy	0.4 - 3 GeV
Pex/Pin	~ 4
Cell number	36
Packing f	0.31
Spiral angle	58
Field index	30
Orbit excursion	0.82 m
Rex/Rin	31.0 / 30.2 m
Bmax@orbit	3.0 (3.3) T
Straight	3.6 m



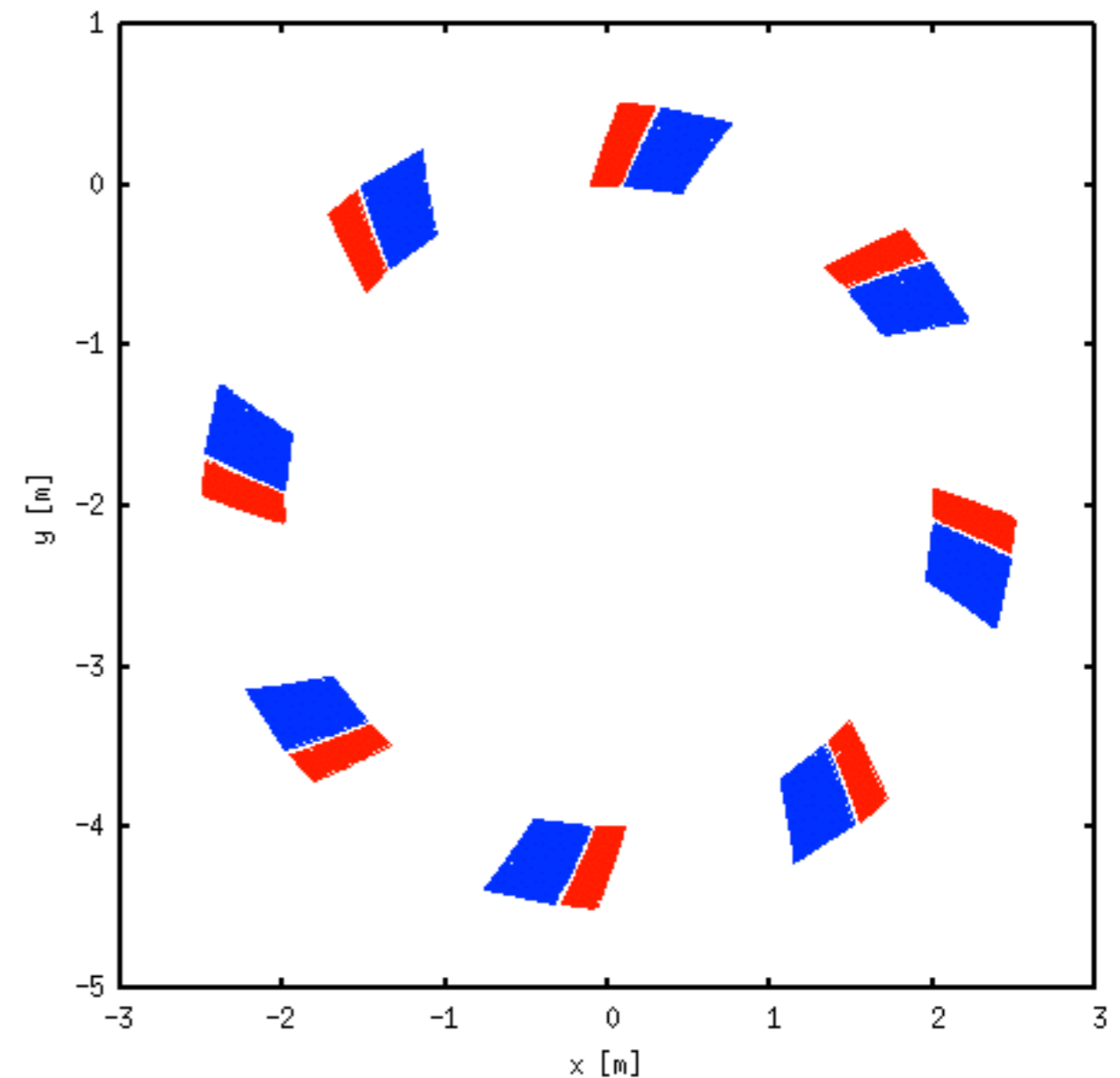
Parameter search

Practically, the best parameter is obtained with the balance between B_{\max} field and spiral angle.



Parameter search

Type	DF-Spiral
Kinetic energy	3 - 27 MeV
Pex/Pin	3
Cell number	8
Packing f	0.31
Spiral angle	20
Field index	3
Orbit excursion	0.48 m
Rex/Rin	2.1 / 2.6 m
Bmax@orbit	1.7 (1.9) T
Straight	1.1 m



More detailed design

- Field with TOSCA
 - More accurate.
- Simulation with space charge and beam loading for high power beams.

What FETS FFAG should demonstrate

- DF-Spiral optics and operation.
- H- injection and extraction.
- Tunability with additional trim coils.
- Non-uniform painting at injection.
- Operation with asymmetric emittance.
- Stacking at the end and shaping time structure.

Possible KURRI/Kyushu experiments

What KURRI/Kyushu should demonstrate

- Non-uniform painting at injection.
- Operation with asymmetric emittance.
- Stacking at the end and shaping time structure.
- Tunability with additional trim coils (Kyushu).

Summary

Summary

- Small scale FFAG proposal is the opportunity given that the 3 MeV high current beam is available.
- New concept of DF-Spiral sector can be tested along with experimental study of high intensity beams.
- In parallel, KURRI/Kyushu experiments are essential to advance our understanding of high power FFAG.

Backup

Before start

- Overview: Design principle (based on RCS 1 MW)
- Lattice design (spiral+ with D magnets)
- Tool development (TOSCA like field)
- Plan of experiments at KURRI and FETS
- Plan of Simulation with space charge
- R&D items (hardware, superferric magnets)

Field model

$$B_z = \frac{\theta - (\theta_1 - \Delta\theta_1/2 + \tan \zeta \ln(r/r_0))}{\Delta\theta_1} B_{z0} \left(\frac{r}{r_0}\right)^k$$

$$B_z = B_{z0} \left(\frac{r}{r_0}\right)^k = z \frac{k}{r} B_{z0} \left(\frac{r}{r_0}\right)^k \quad B_\theta = \frac{z}{r \Delta\theta_1} B_{z0} \left(\frac{r}{r_0}\right)^k$$

$$B_r = z \frac{k(\theta - (\theta_1 - \Delta\theta_1/2 + \tan \zeta \ln(r/r_0))) - \tan \zeta}{r \Delta\theta_1} B_{z0} \left(\frac{r}{r_0}\right)^k$$

$$B_z = \frac{(\theta_2 + \Delta\theta_2/2 + \tan \zeta \ln(r/r_0)) - \theta}{\Delta\theta_2} B_{z0} \left(\frac{r}{r_0}\right)^k$$

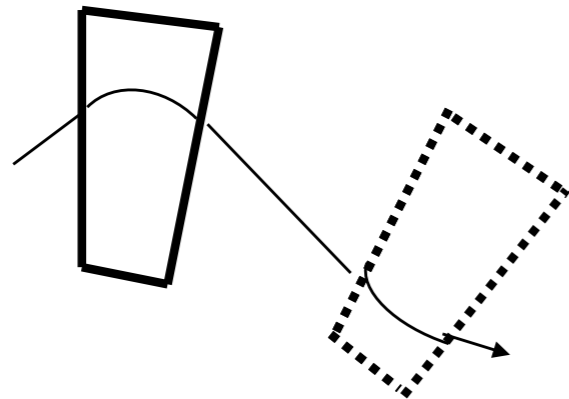
$$B_\theta = -\frac{z}{r \Delta\theta_2} B_{z0} \left(\frac{r}{r_0}\right)^k$$

$$B_r = z \frac{k((\theta_2 + \Delta\theta_2/2 + \tan \zeta \ln(r/r_0)) - \theta) + \tan \zeta}{r \Delta\theta_2} B_{z0} \left(\frac{r}{r_0}\right)^k$$

Lattice design with new idea

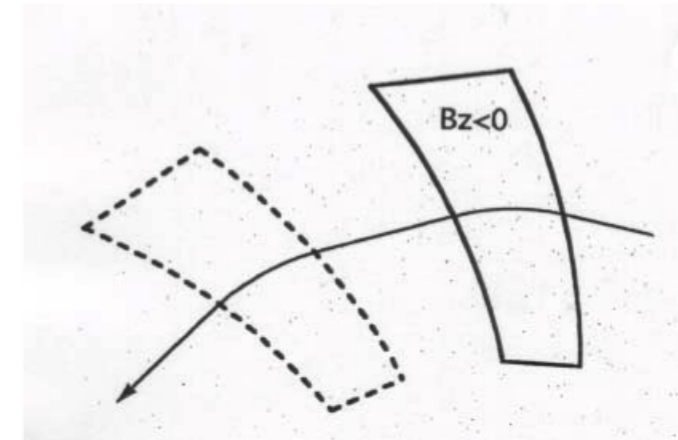
Radial or Spiral FFAG

radial sector

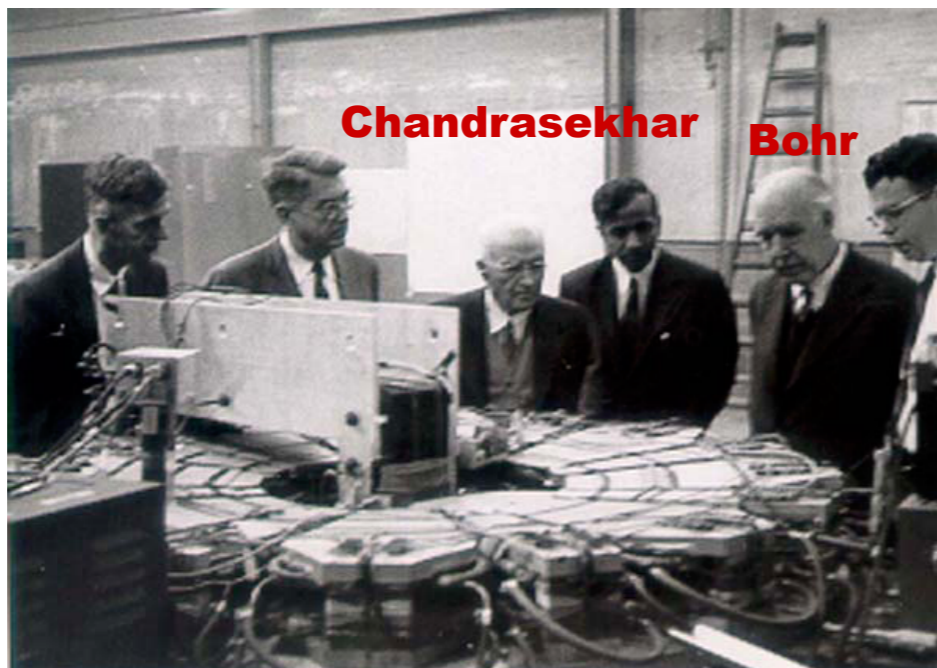


Alternating gradient focusing by focusing (normal bend) and defocusing (**reserve bend**)

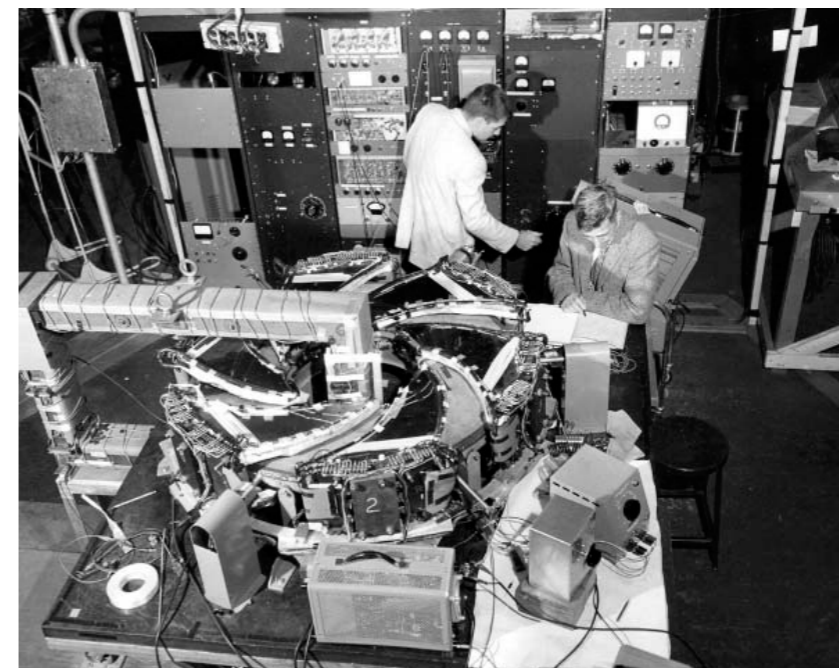
spiral sector



Alternating gradient focusing by focusing (normal bend) and defocusing (**edge angle**)



400 keV radial sector

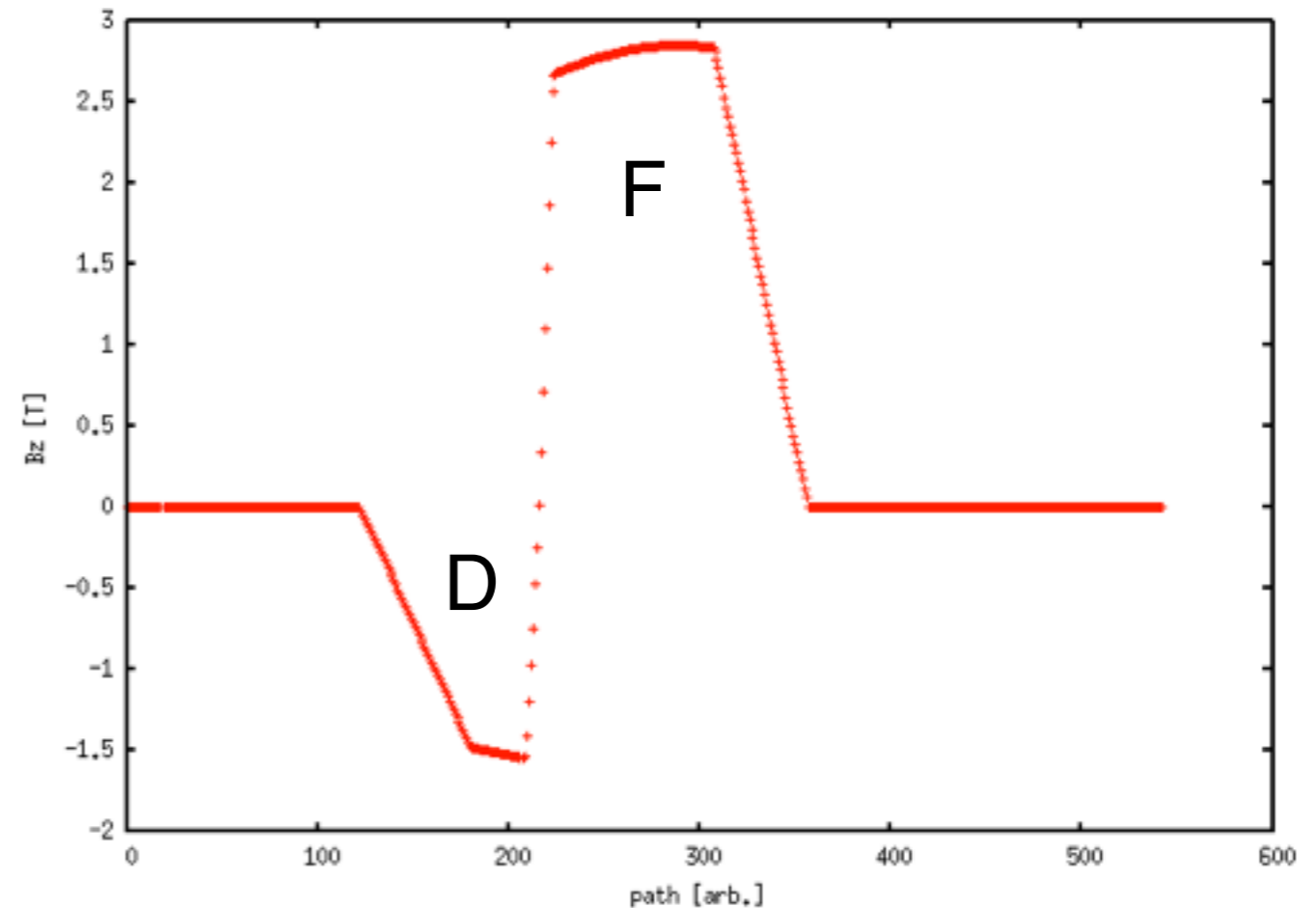
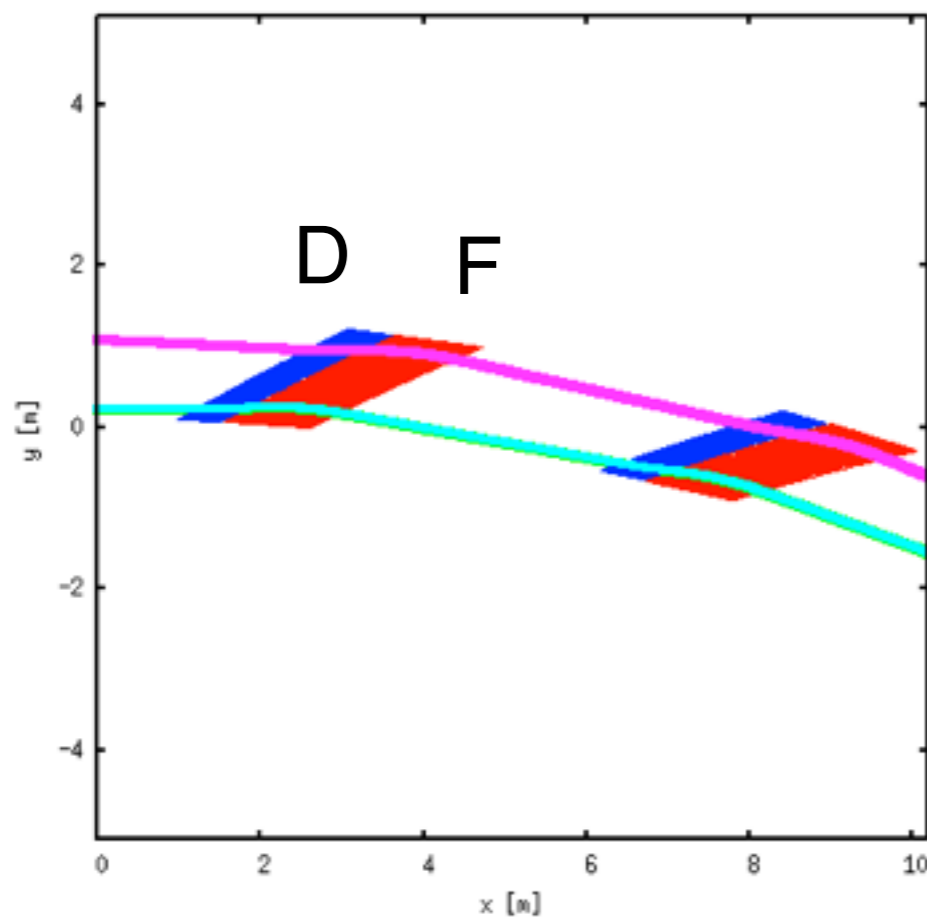


180 keV spiral sector



DF-Spiral FFAG

- New idea: *DF-Spiral*
 - Introduce (small) negative field on one side of the main spiral magnet.



- Shape edge is created between D and F.
- Field flutter increases.
- Knob of F/D ratio like radial type.

Magnetic field profile

DF-Spiral FFAG

