Advanced Scaling FFAG

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Outline

- Introduction
- “Advanced” Scaling FFAG ingredients
- Study of “Advanced” Scaling FFAG: experiment at KURRI
- Examples of applications

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“Classic” Scaling FFAG

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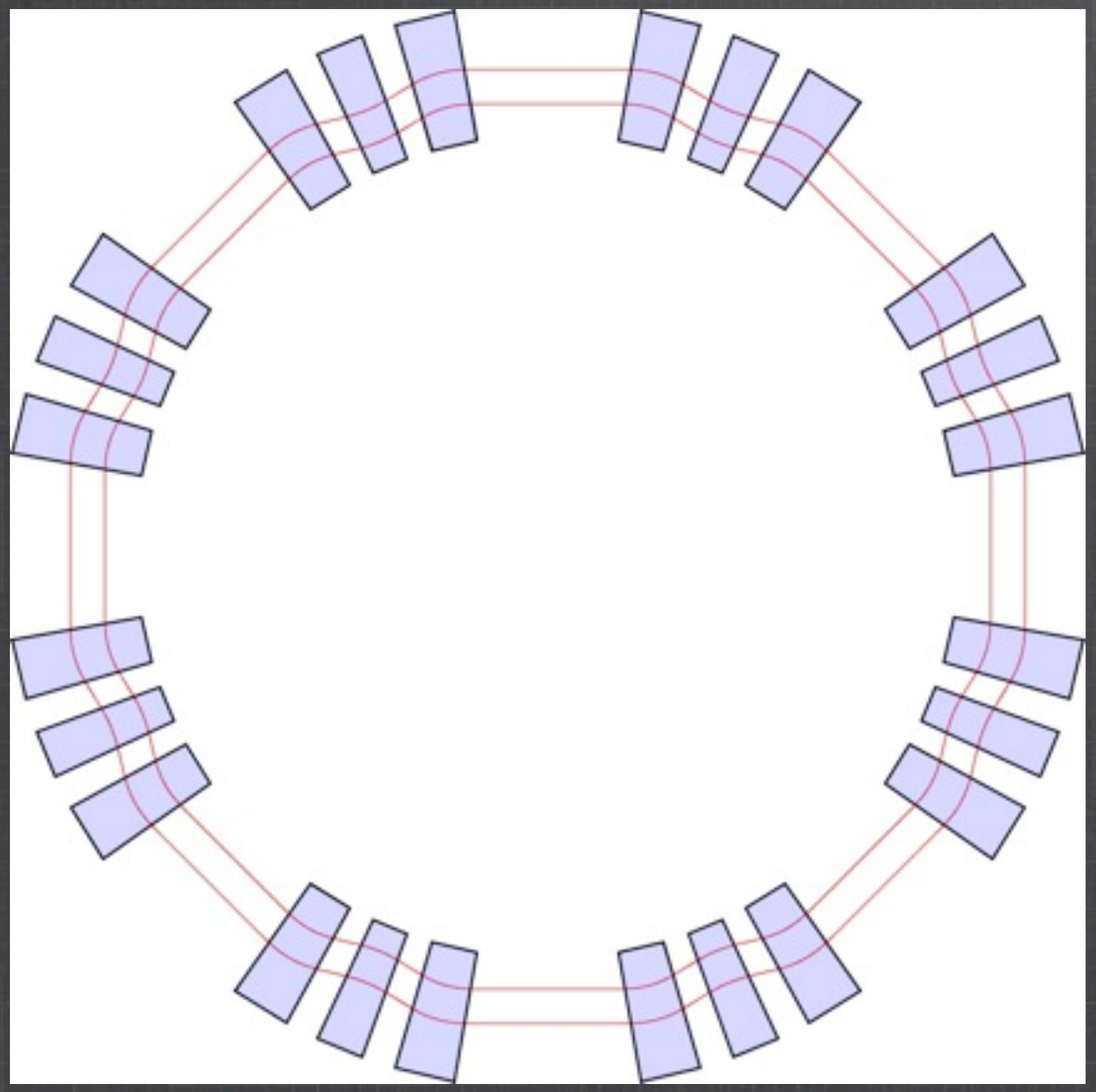

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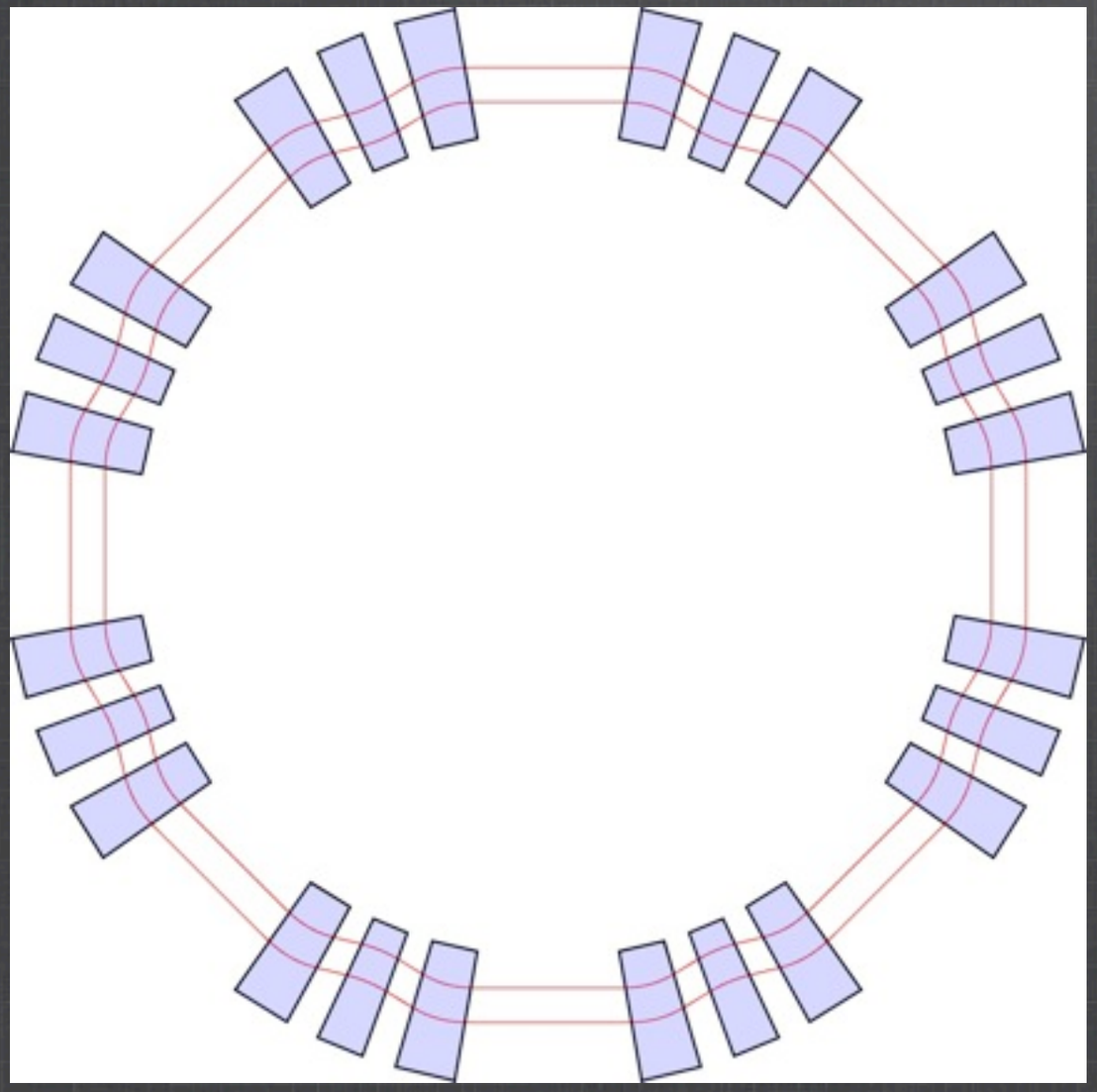

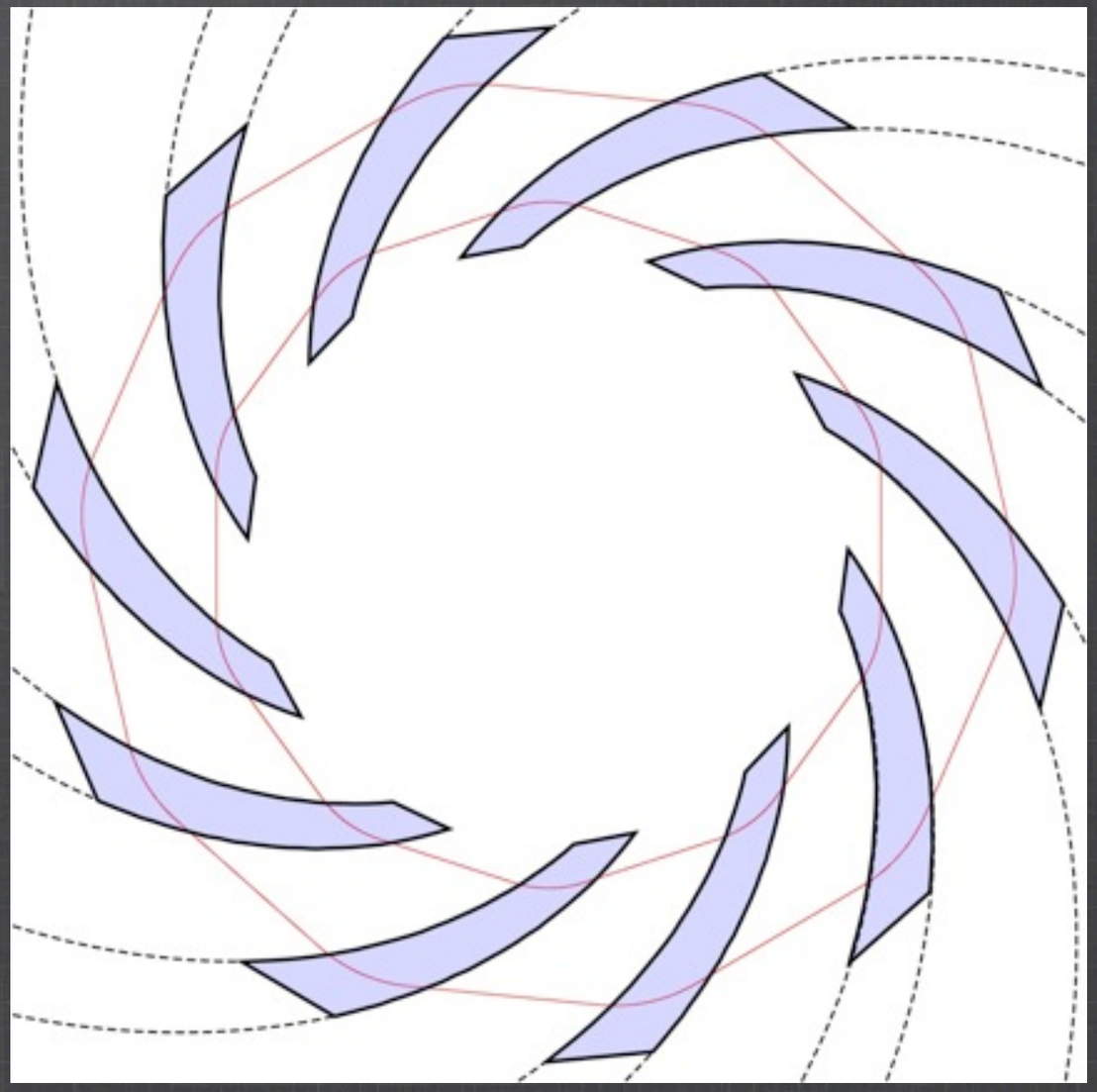

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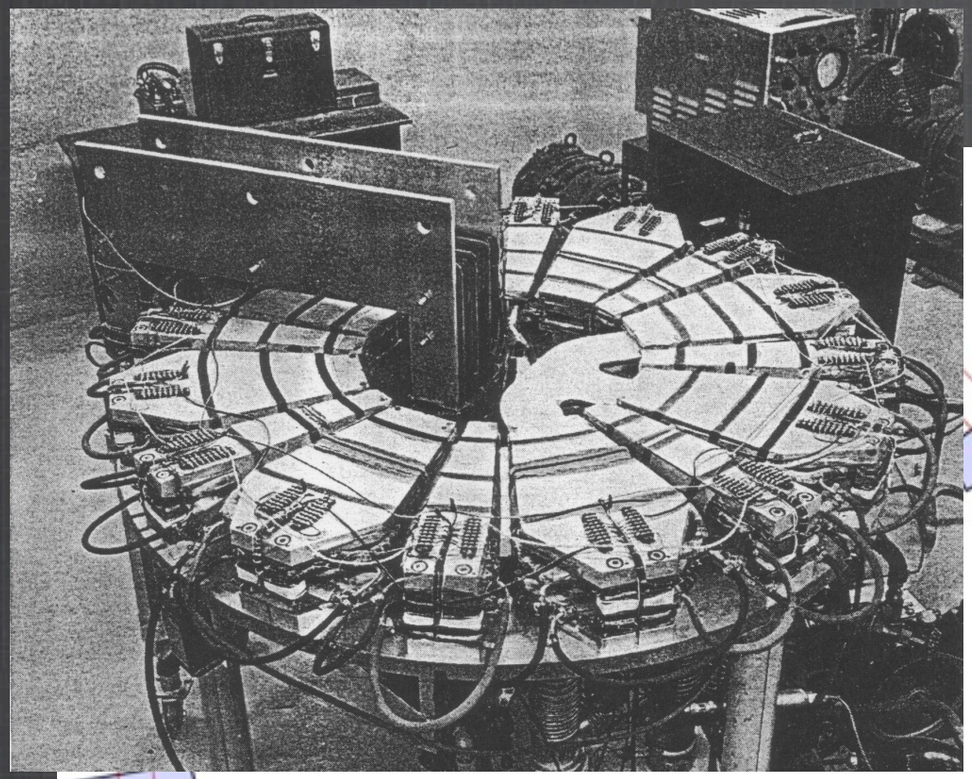

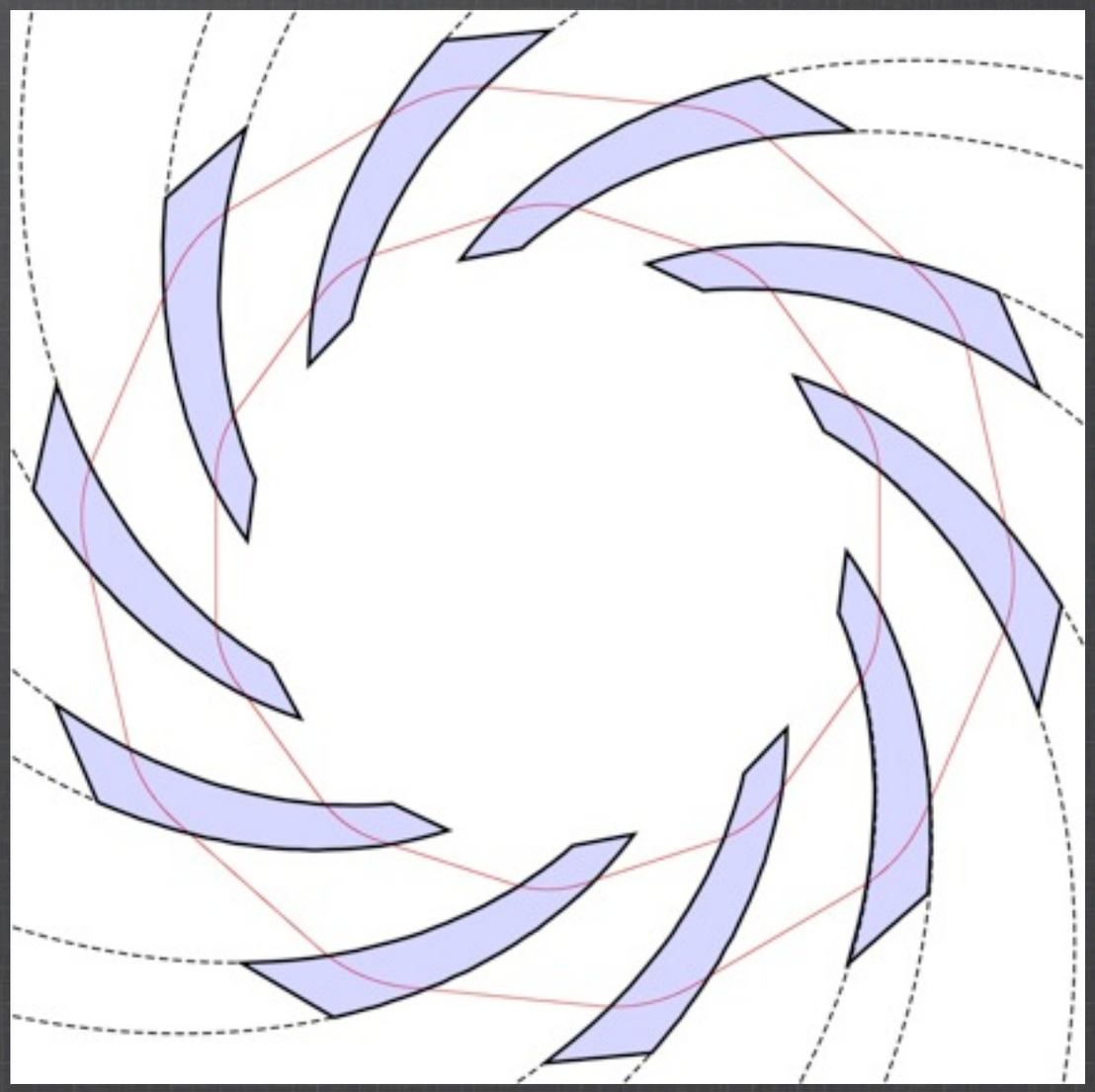

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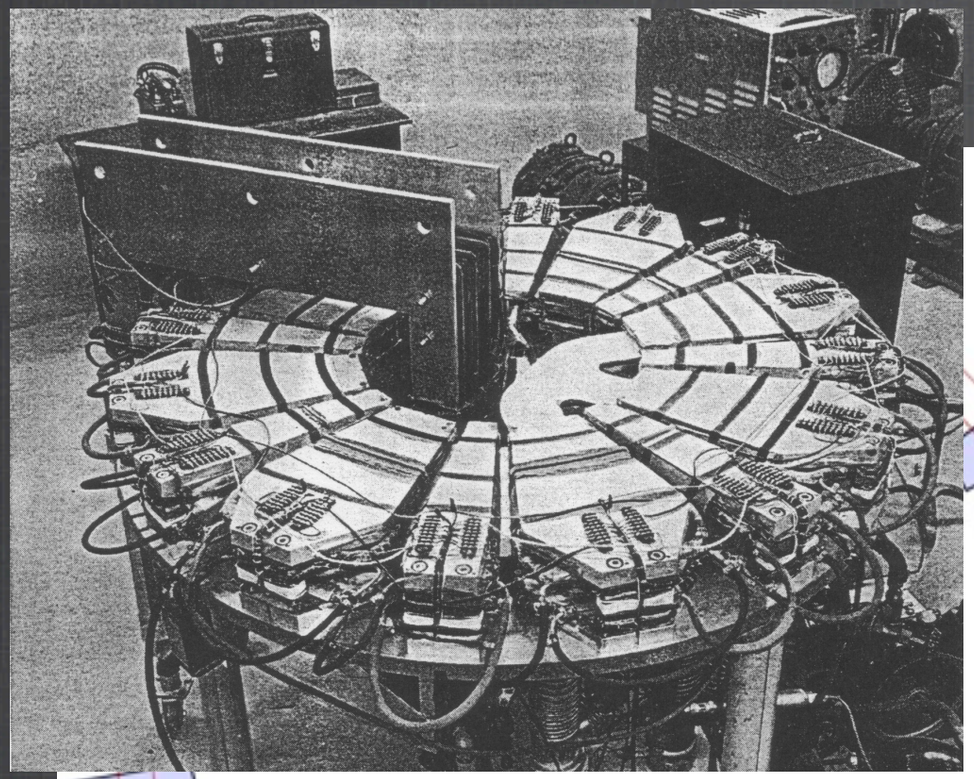

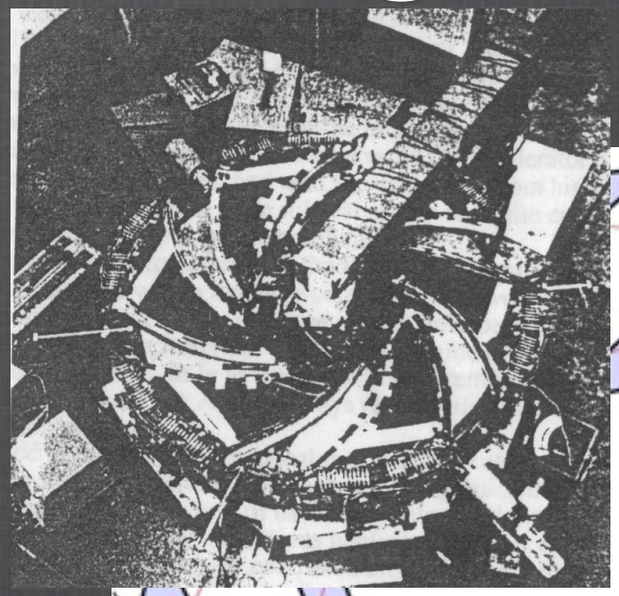

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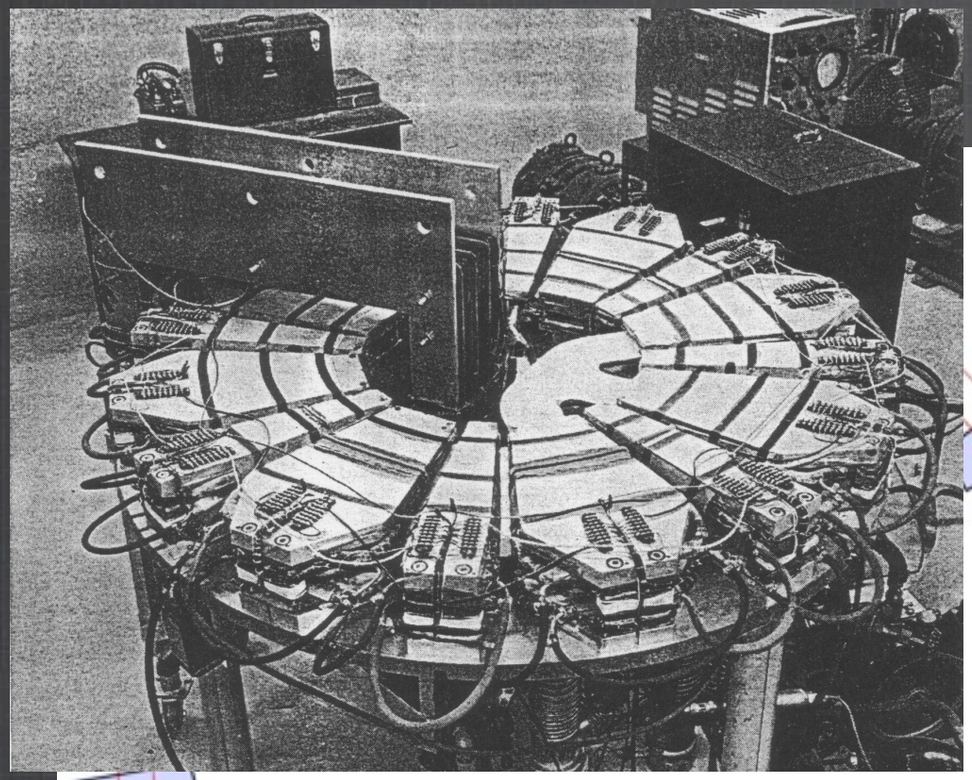

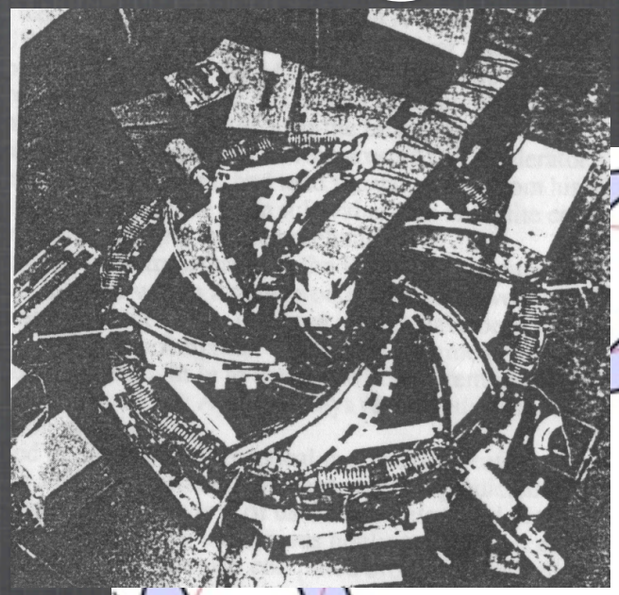

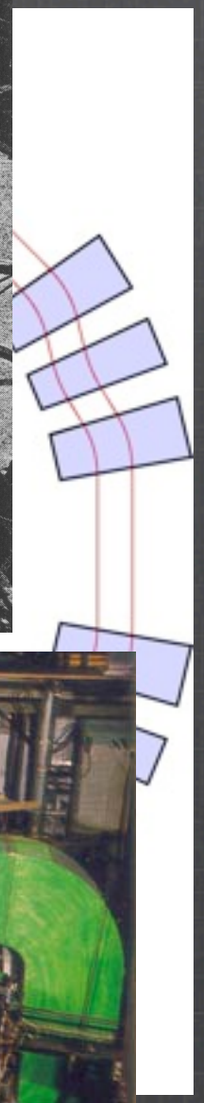

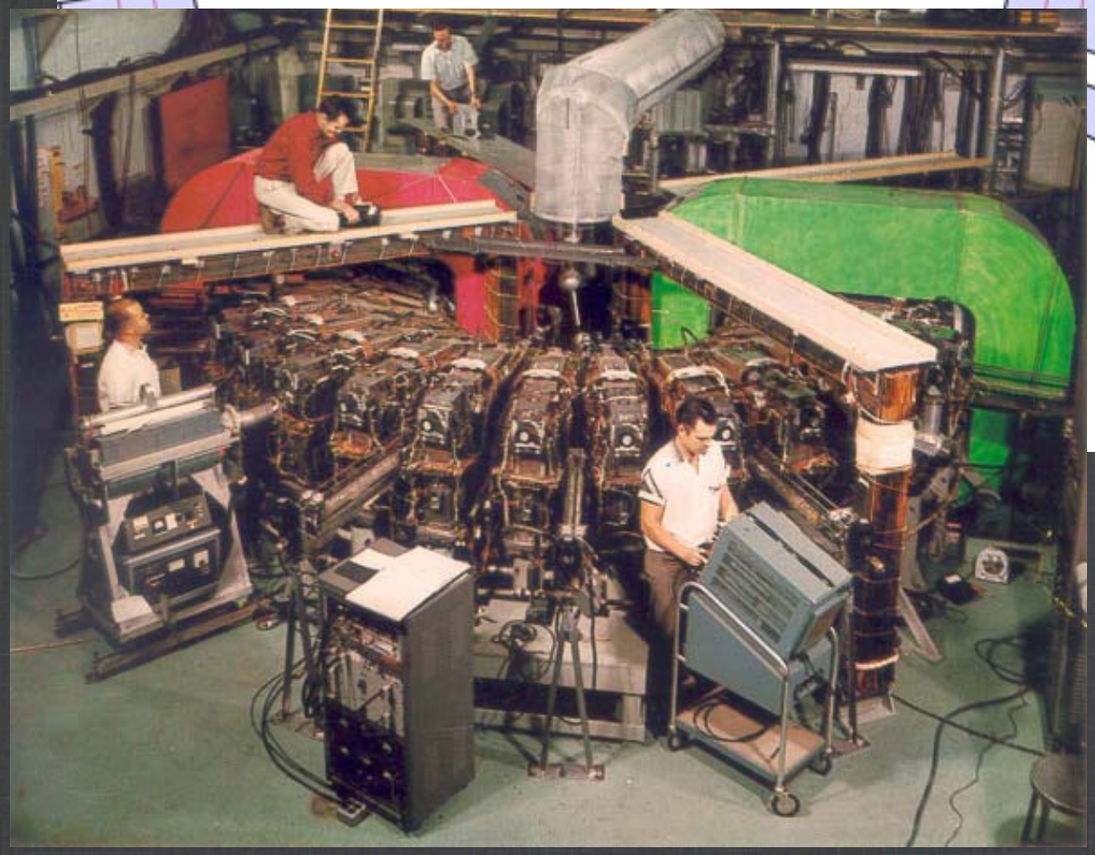

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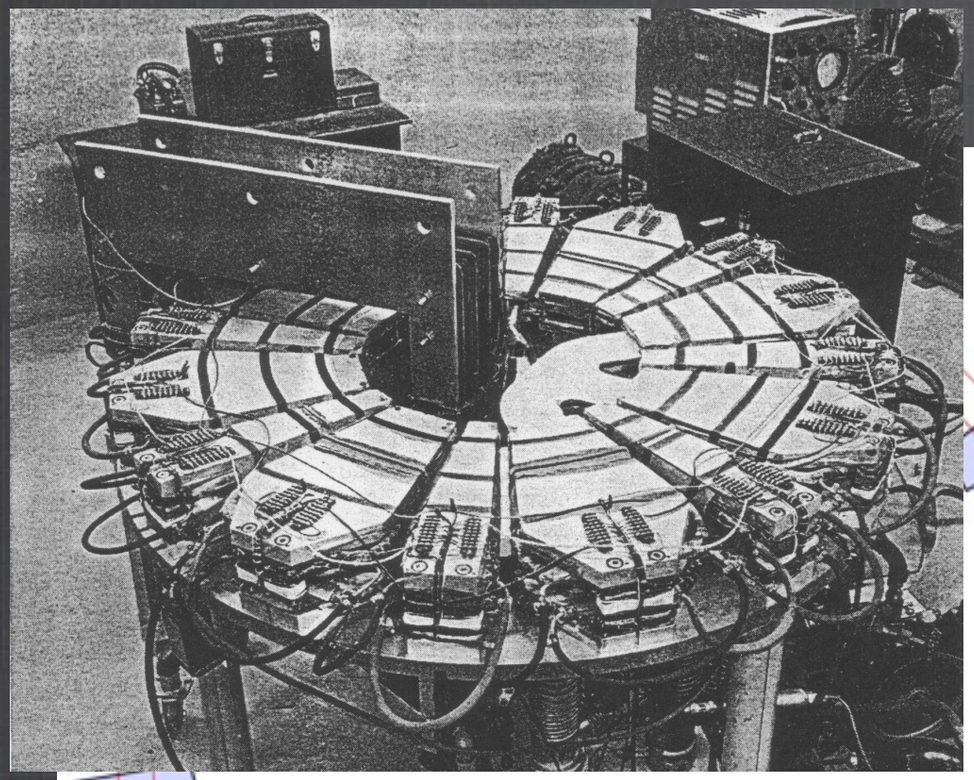

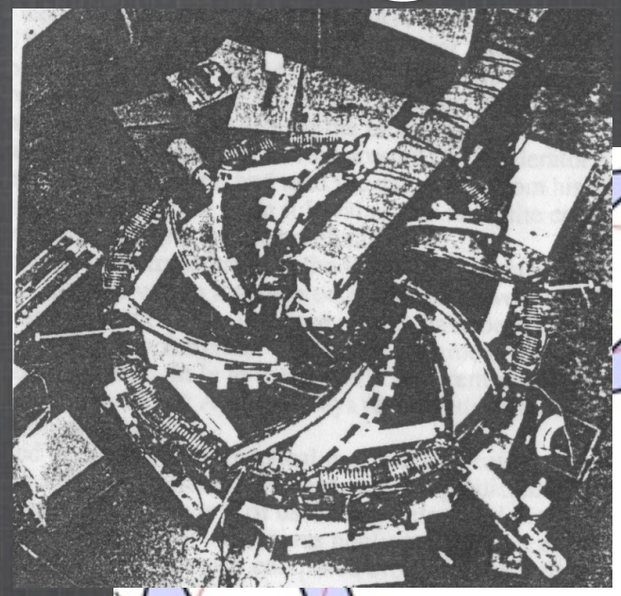

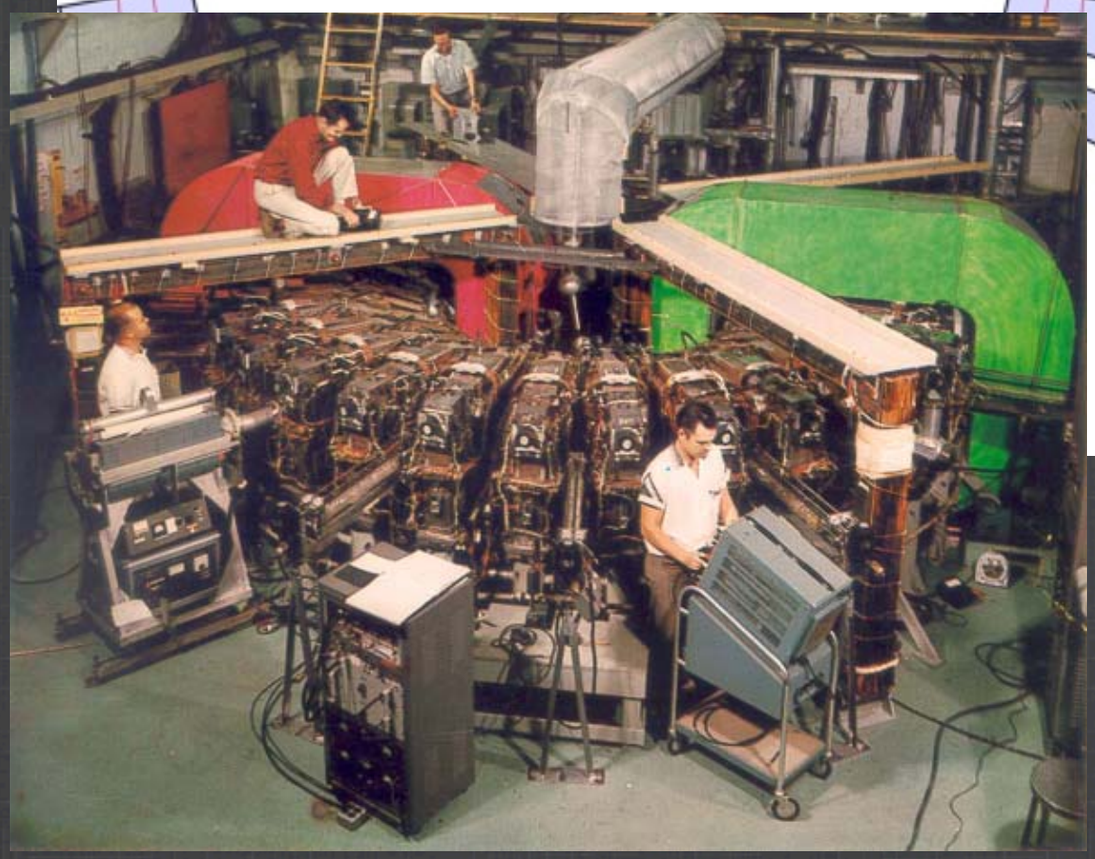

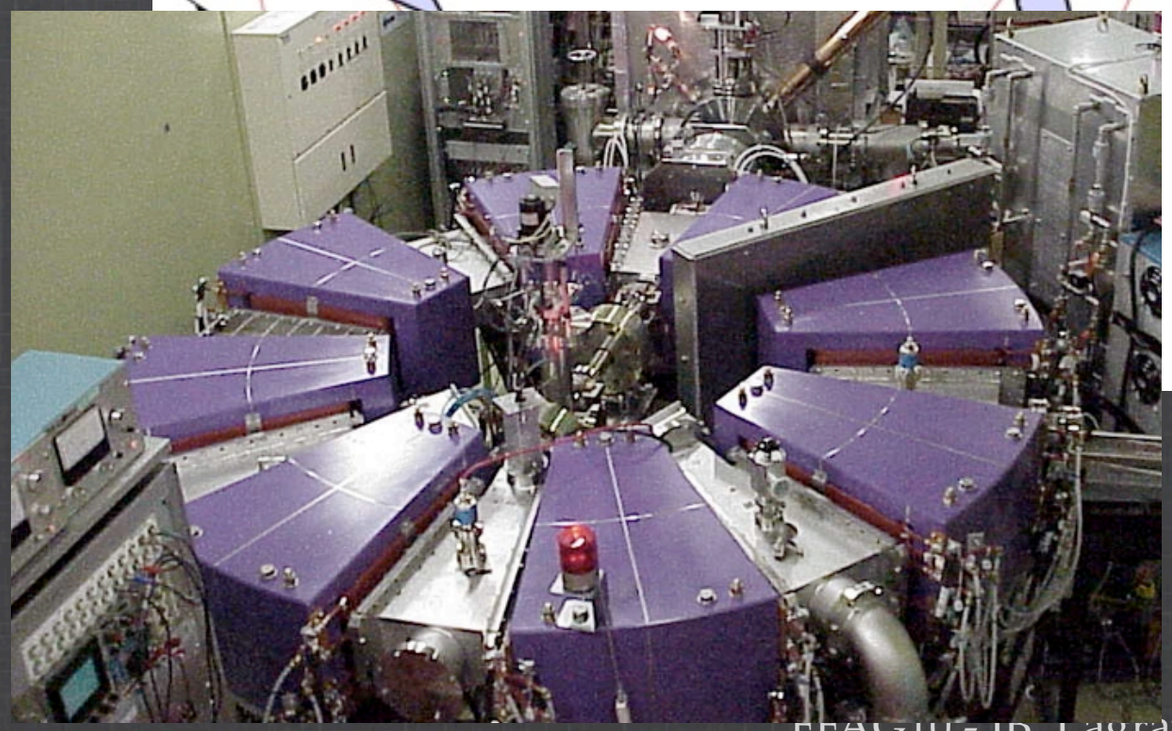

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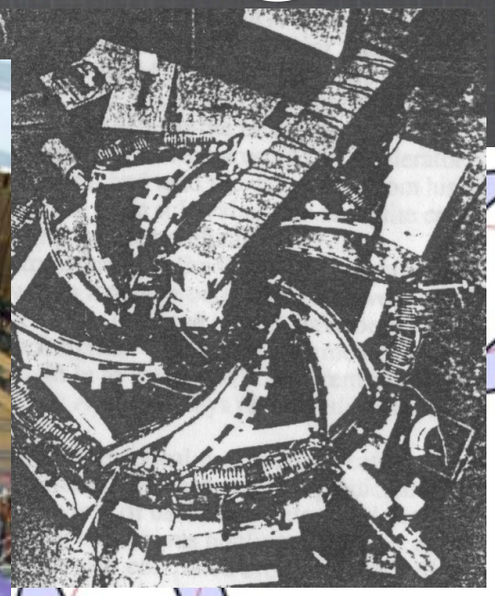

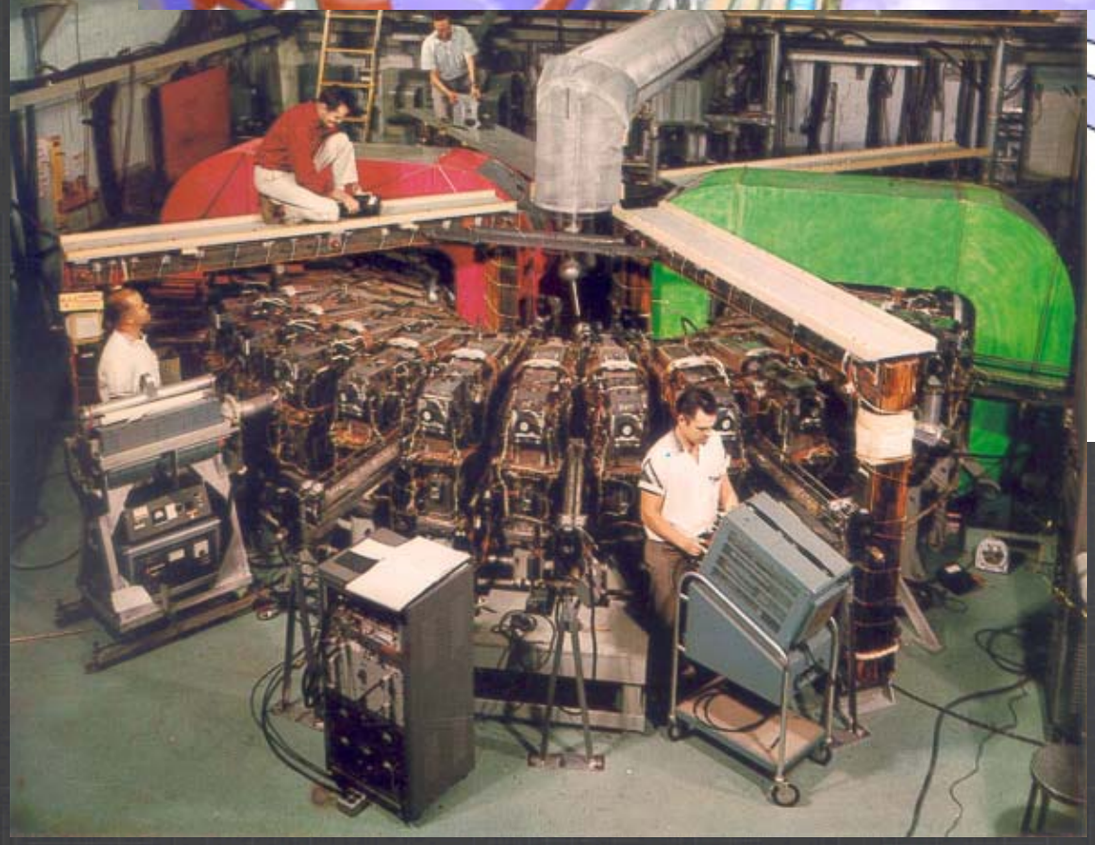

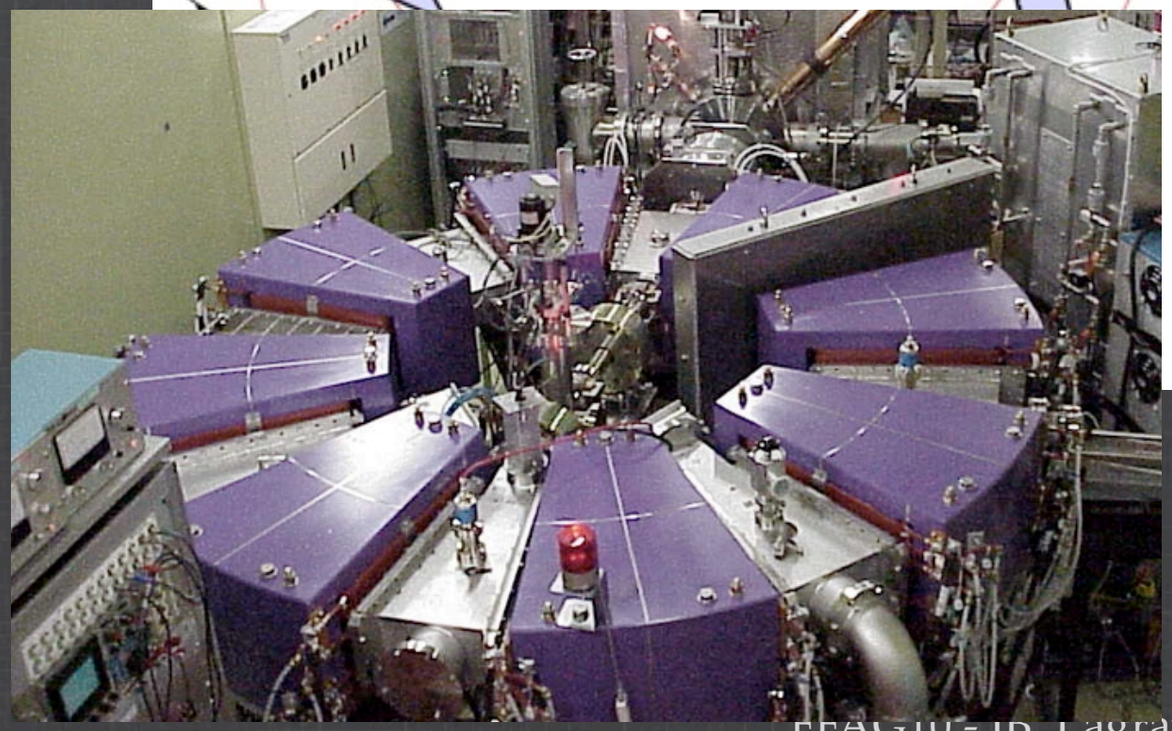

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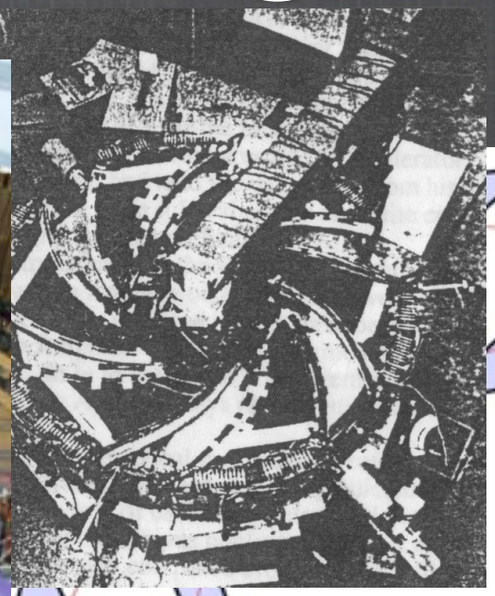

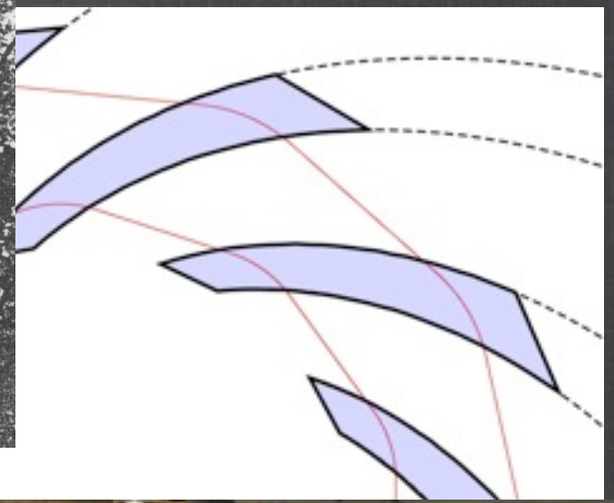

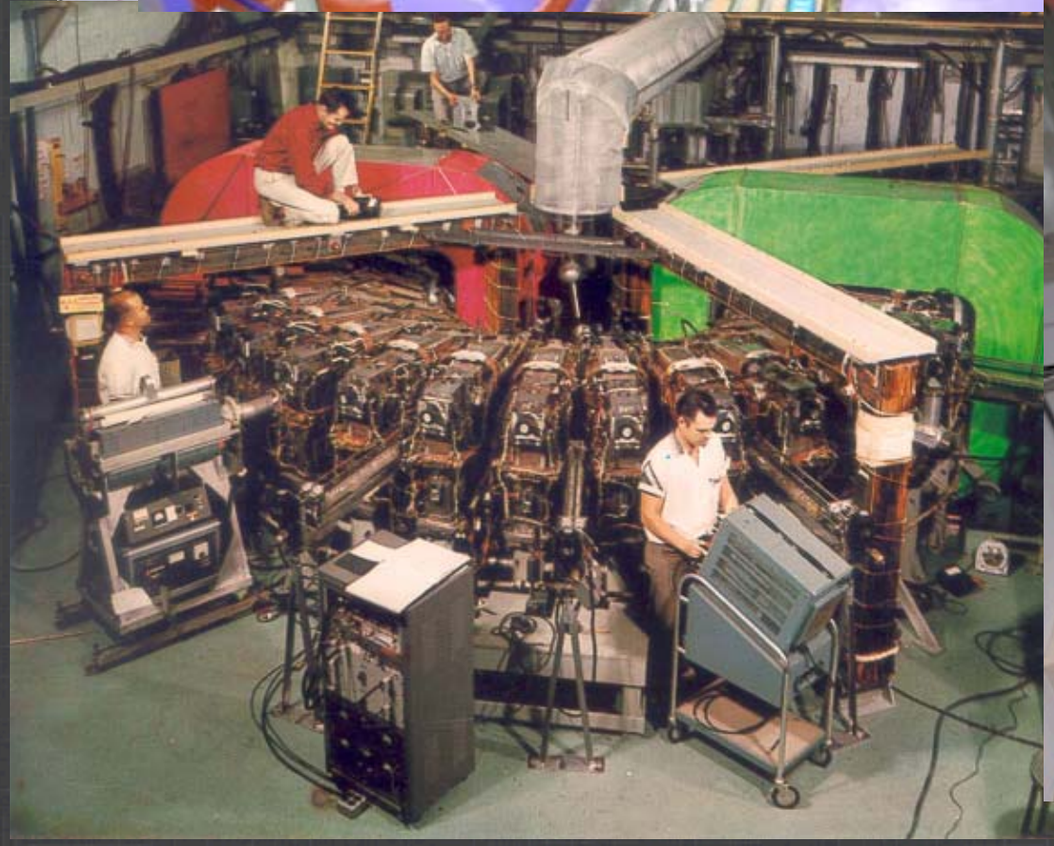

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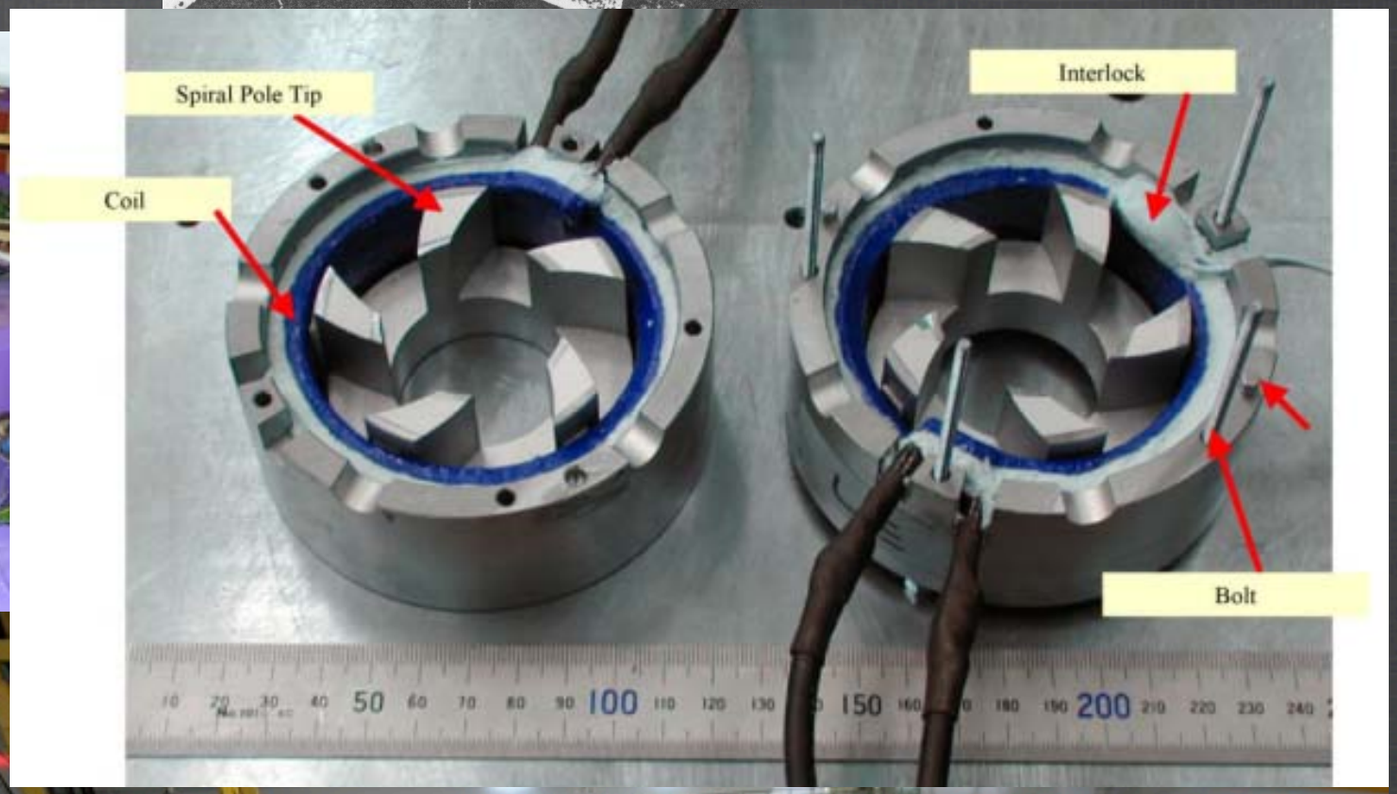

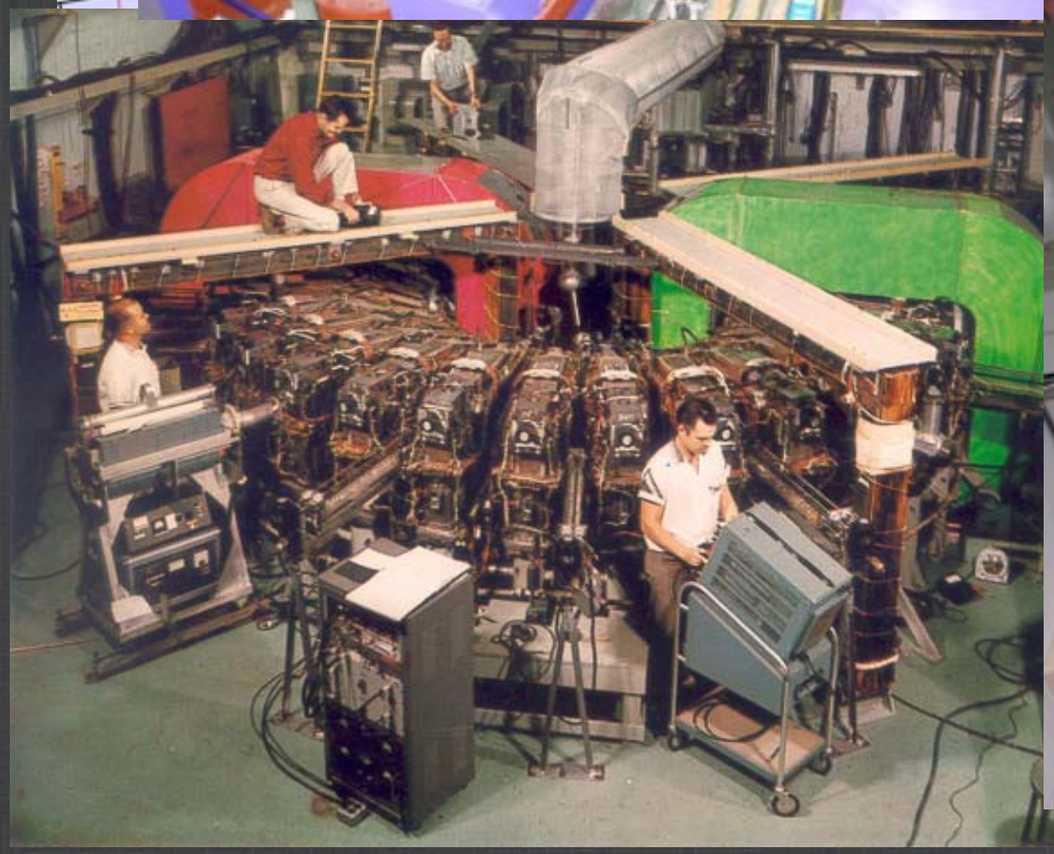

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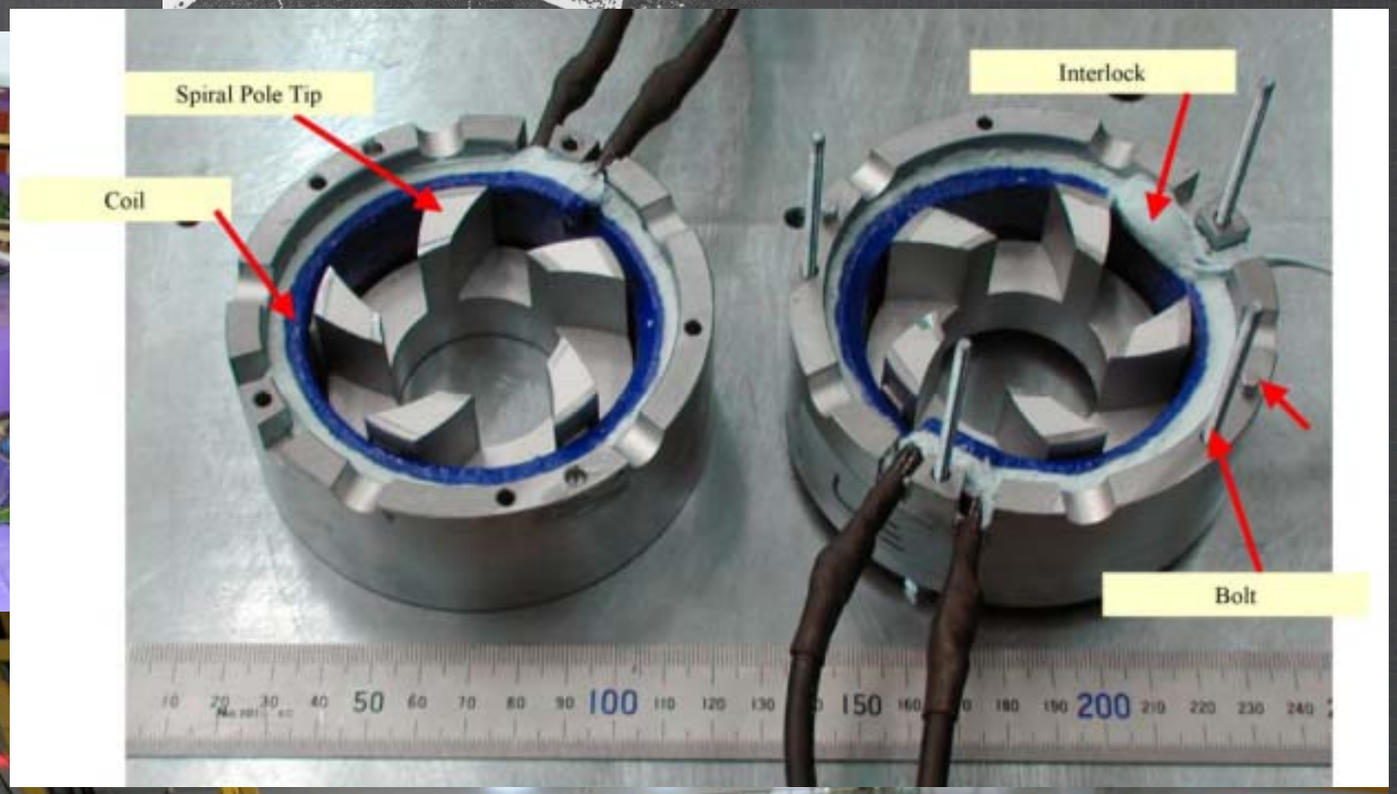

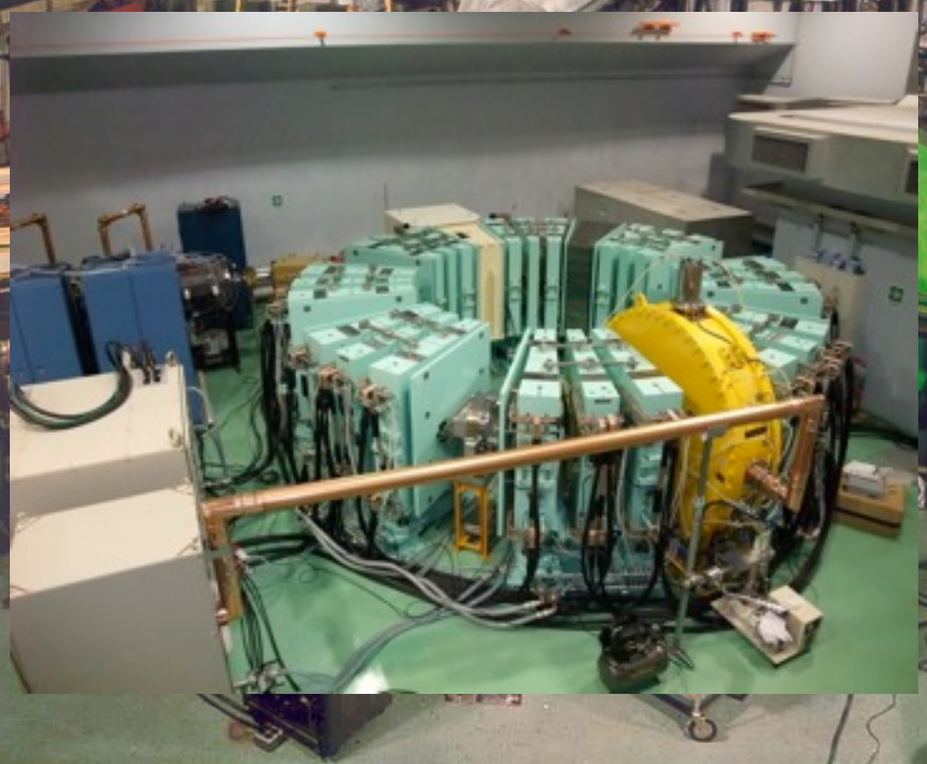

"Classic" Scaling FFAG

- Perfectly round shape
- One type of cell
- Constant large excursion: limitations for cavities

→ Can it be improved?

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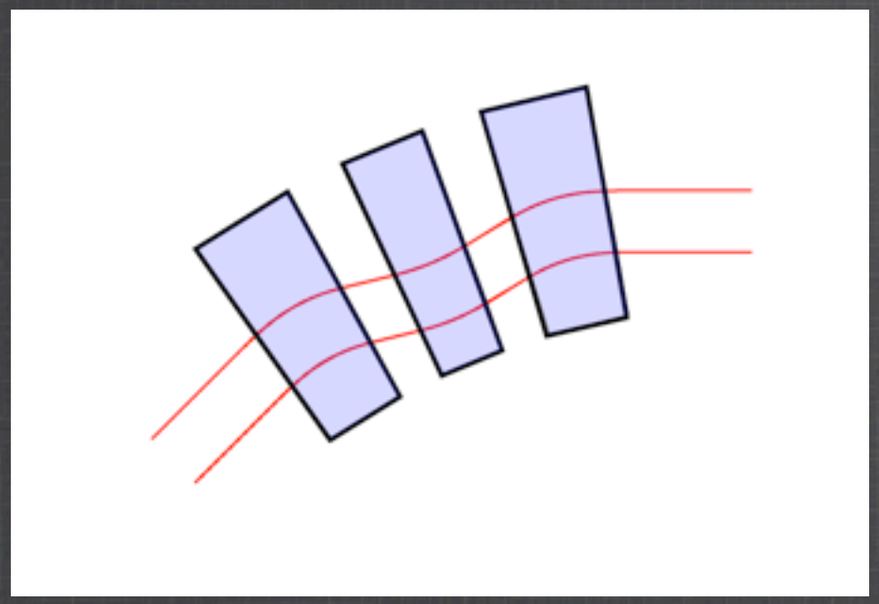
- Examples of applications

Scaling law

Bending case



- Similarity of the closed orbits
-Invariance of the betatron oscillations

Magnetic field: $B_z = B_0 \left(\frac{r}{r_0}\right)^k$

with $k = \frac{r}{B}\left(\frac{\partial B_z}{\partial r}\right)$

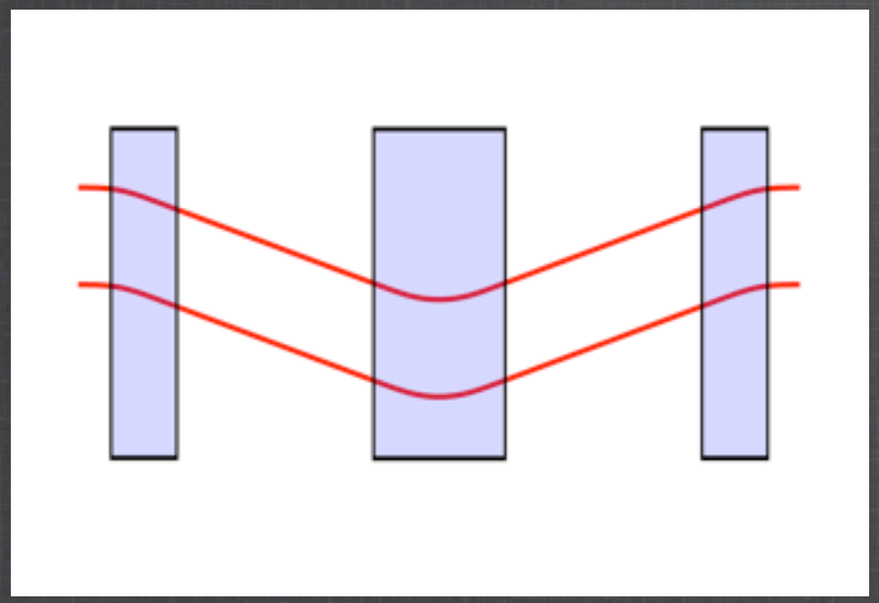
NB: In the linear approximation, $k = \frac{r}{\rho} n$

Momentum compaction factor: $\alpha = \frac{1}{k+1}$

Dispersion function: $D(p_0) = p_0 \left(\frac{\partial r}{\partial p}\right)_{p_0} = \frac{r}{k+1}$

Scaling law

Straight case



- Similarity of the closed orbits
-Invariance of the betatron oscillations

Magnetic field: $B_z = B_0 e^{m(x-x_0)}$

with $m = \frac{1}{B}\left(\frac{\partial B_z}{\partial x}\right)$

NB: In the linear approximation, $m = \frac{n}{\rho}$

Momentum compaction factor: $\alpha = 0$

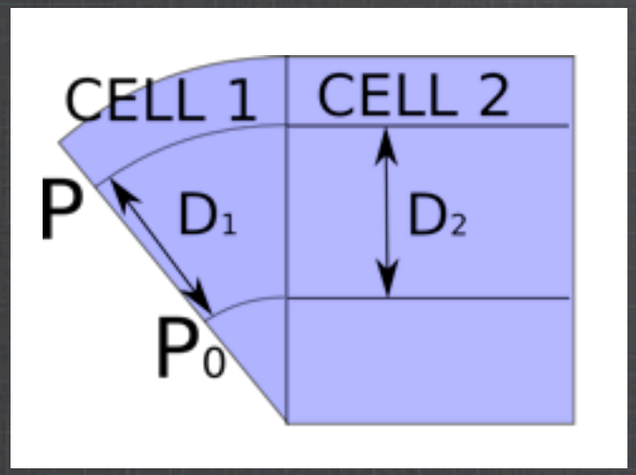
Dispersion function: $D(p_0) = p_0 \left(\frac{\partial x}{\partial p}\right)_{p_0} = \frac{1}{m}$

Linear approx.: $\lim_{r_0 \to \infty} \left(\frac{r}{r_0}\right)^k = \lim_{r_0 \to \infty} \left[\left(1+\frac{x}{r_0}\right)^{\frac{r_0}{x}}\right]^{\frac{x}{r_0}k} = \left[\lim_{r_0 \to \infty}\left(1+\frac{x}{r_0}\right)^{\frac{r_0}{x}}\right]^{\frac{n}{\rho}x} = e^{\frac{n}{\rho}x} = e^{mx}$

Insertions

Matching of different scaling FFAG cells

1) Matching of the closed/reference orbits



a) Matching of a special momentum P_0.

b) Matching to the first order in $\Delta R/R_0$ by matching of the dispersion of the different cells.

2) Matching of the periodic linear parameters

As much as possible (the more the better)

Often difficult → π-phase advance for one of the cell(s)

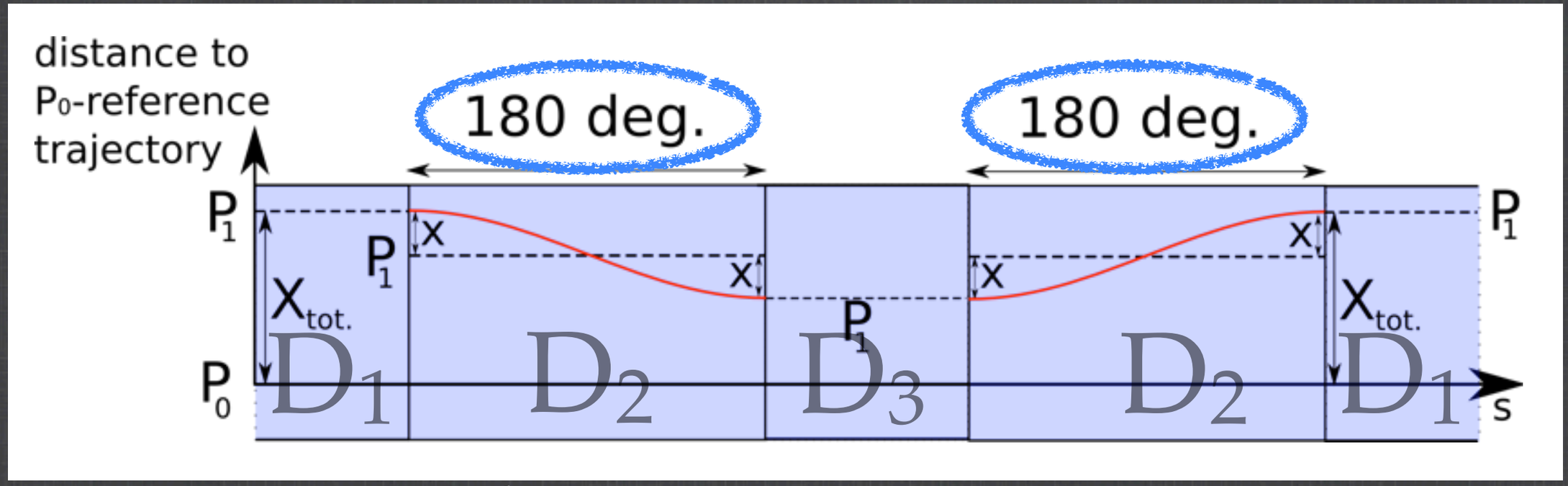
Insertions

Dispersion suppressor principle

Use of 3 different scaling FFAG cells

a) Matching of a special momentum P_0.

b) Matching of periodic dispersions such as $D_2 = \frac{D_1 + D_3}{2}$



Zero-chromatic system as long as amplitude detuning can be neglected.

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Study of Advanced Scaling FFAG

In Kyoto University, an experiment is planned to be conducted in order to study these new tools.

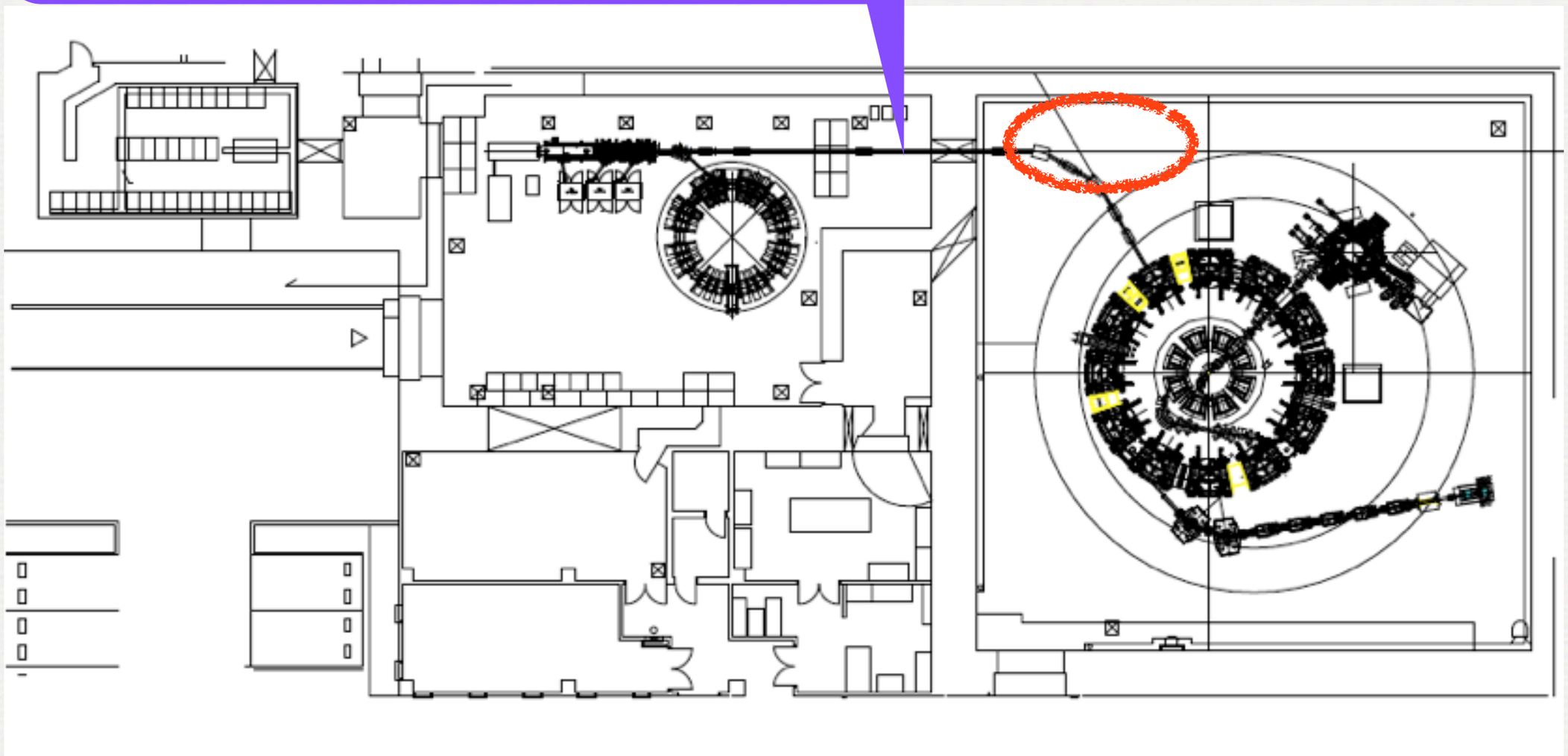
2 goals for this experiment:

- Verify the straight field law,
- Verify and study the dispersion suppressor principle.

Experiment

Layout of the experiment

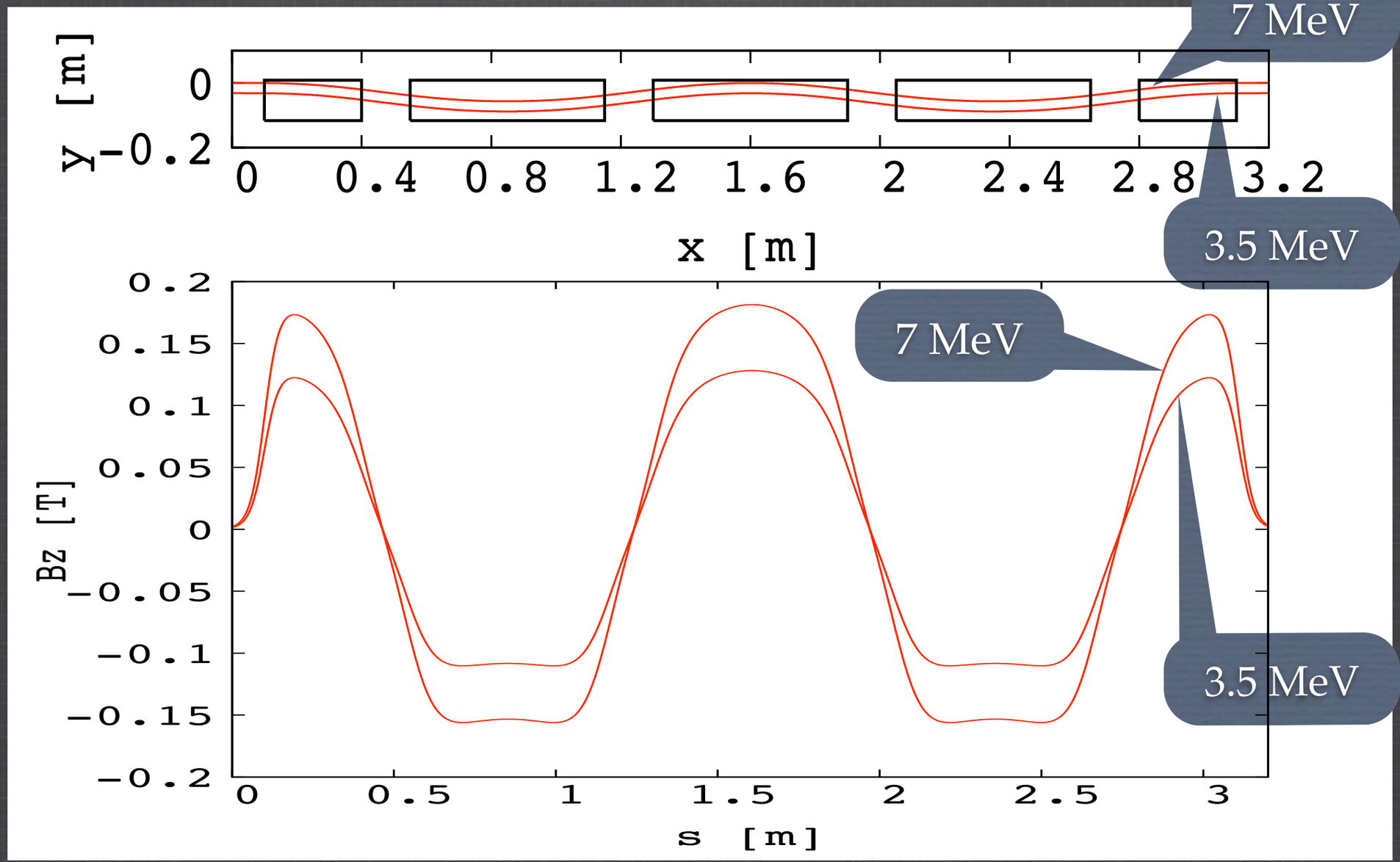
H- linac injection beam line



Use of 2 energies: 3.5 MeV and 7 MeV.

Experiment

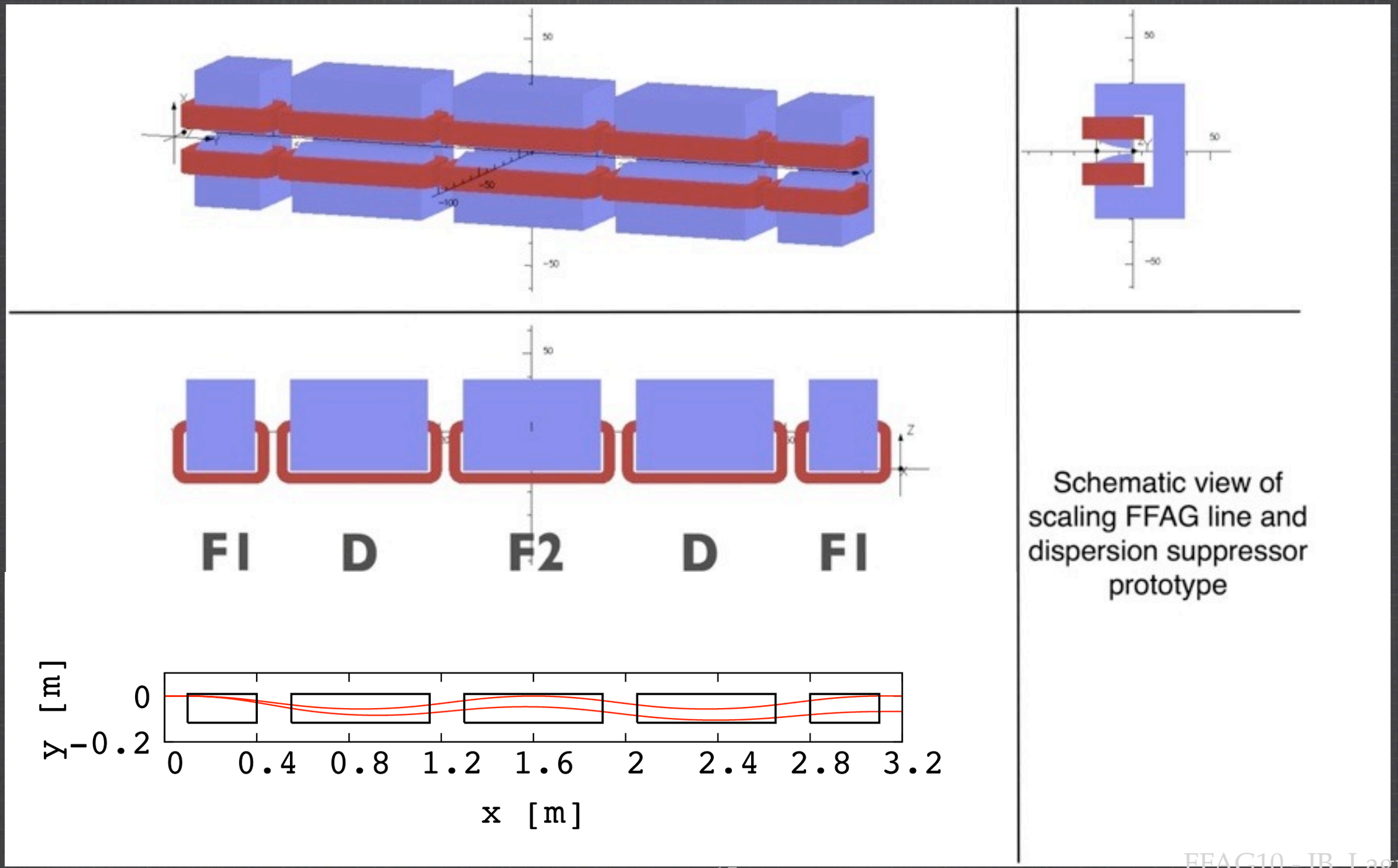
Straight field law



Use of steering magnets for the shifts of the orbits

Experiment

Dispersion suppressor and magnets



Schematic view of scaling FFAG line and dispersion suppressor prototype

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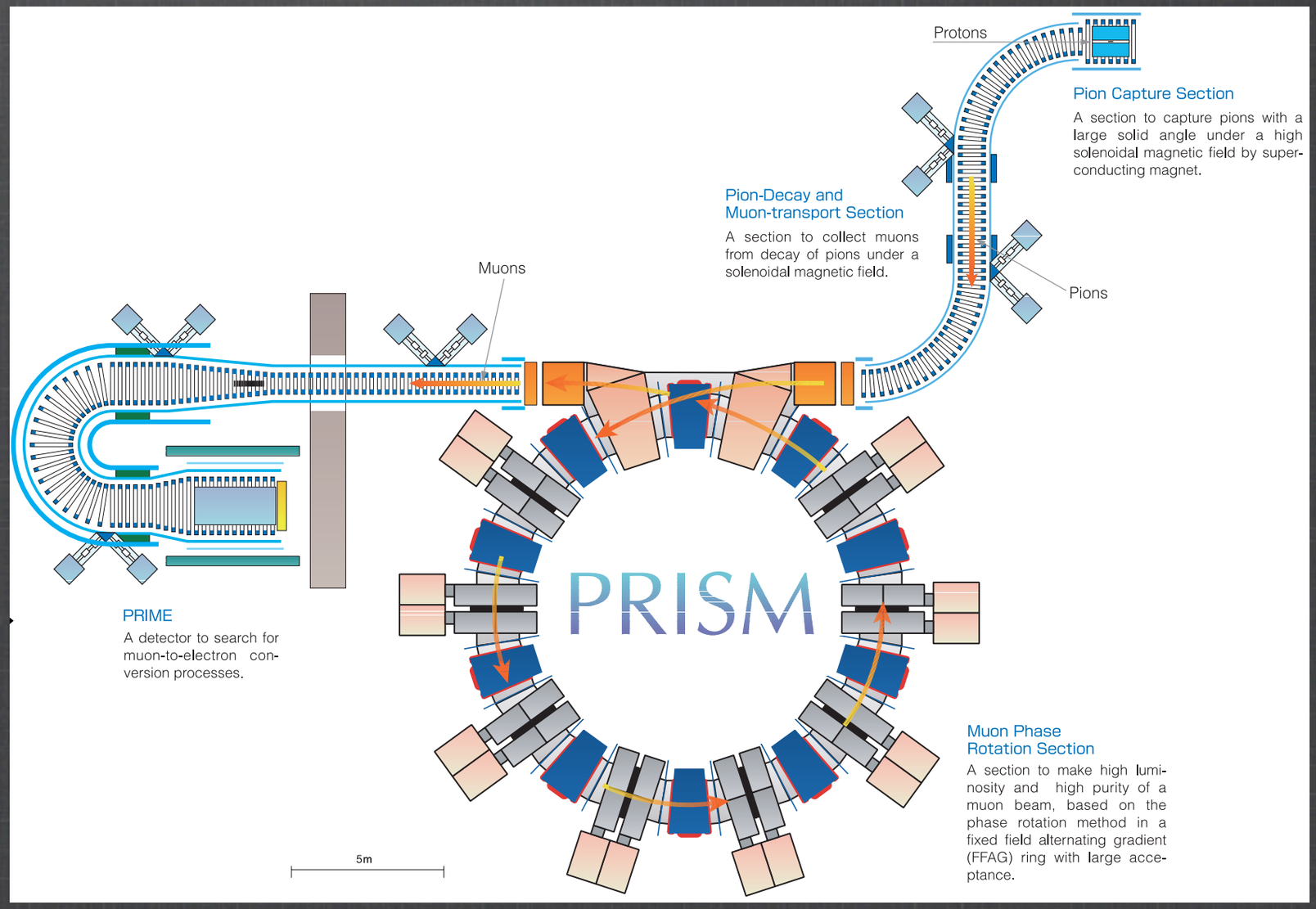
Applications

PRISM project

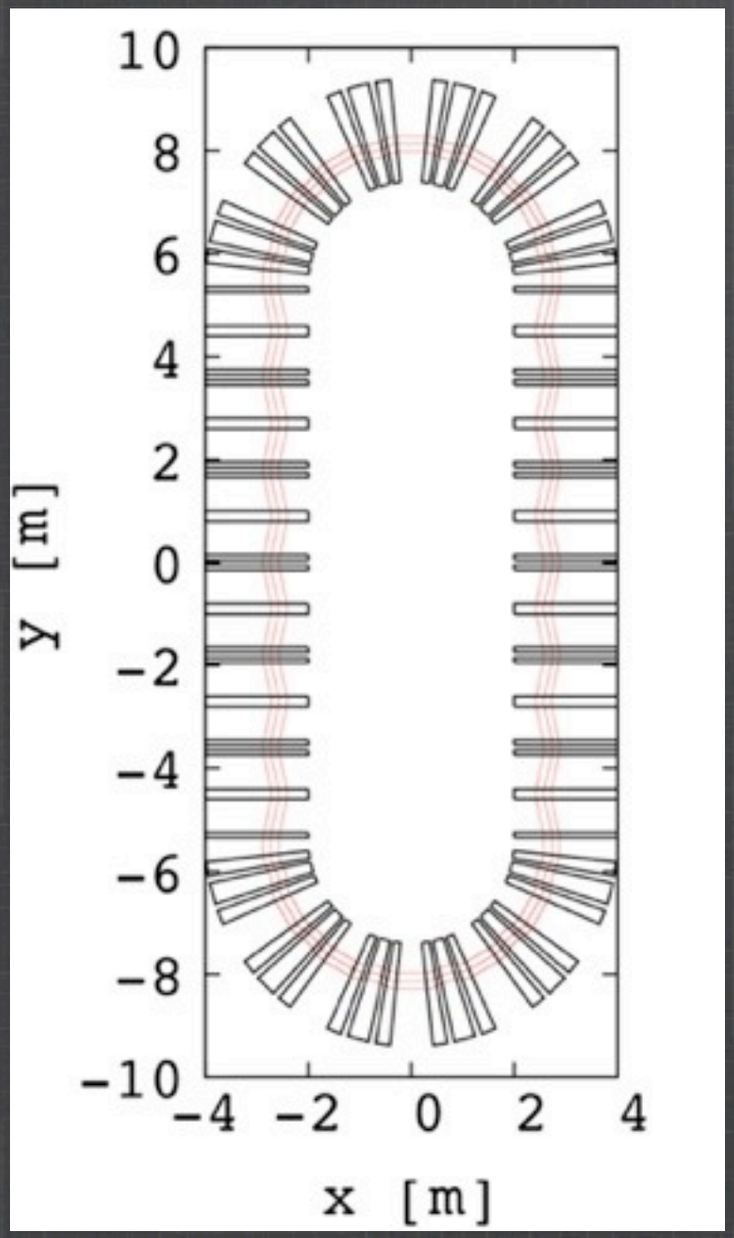
Muon phase rotator (at Osaka University)

- Momentum acceptance: 68MeV / c ± 20%
- Transverse acceptance:
  - hor.: 30 000π mm.mrad
  - vert.: 3 000π mm.mrad



Applications

Race-track scaling FFAG PRISM

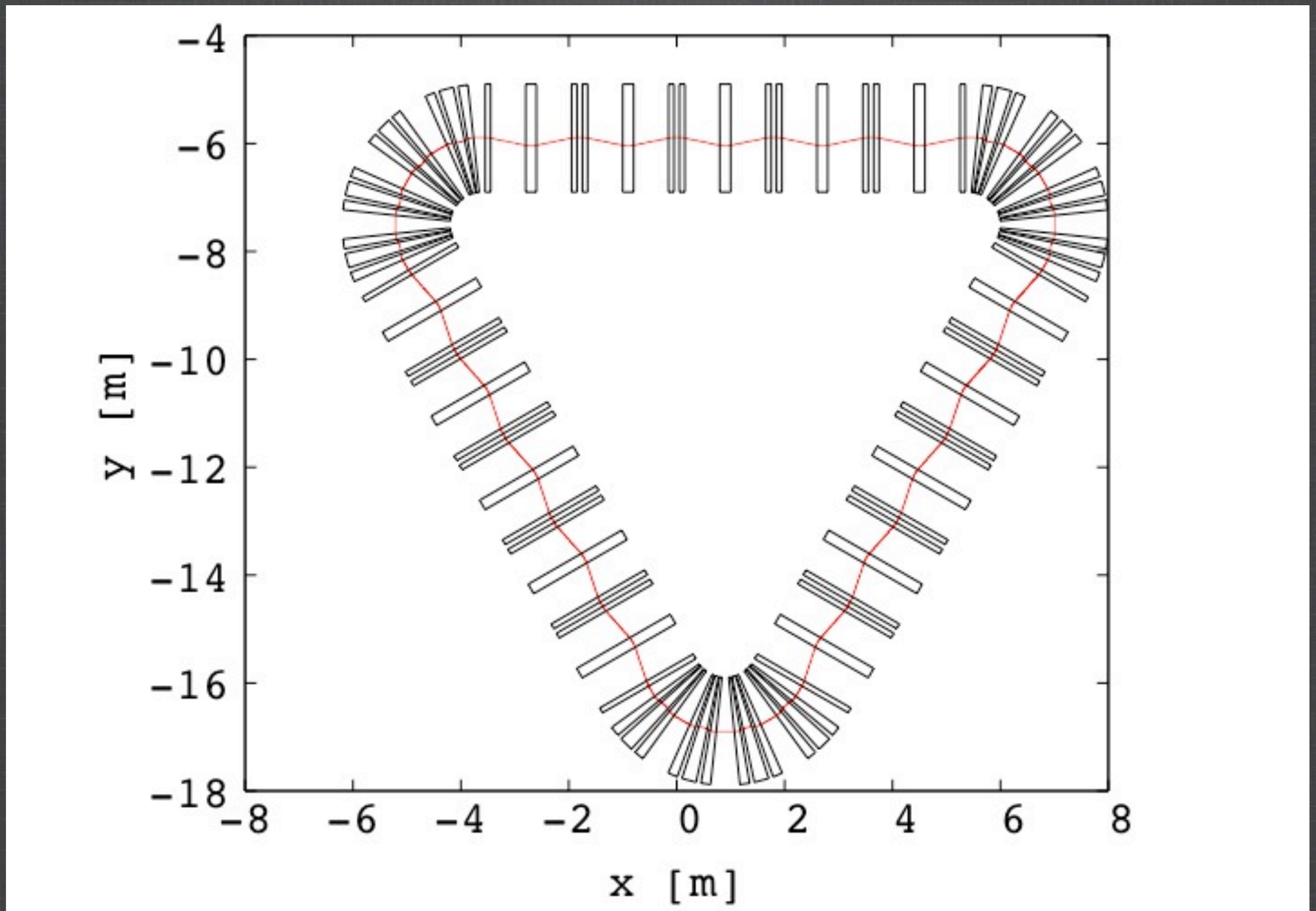


Bending cell FDF triplet	
k-value	2.55
Average radius	2.7 m
Phase advances:	
Horizontal μ_x	60 deg.
Vertical μ_z	90 deg.
Dispersion	0.8 m

Straight cell	
m-value	$1.3\,\mathrm{m}^{-1}$
Length	1.8 m
Phase advances:	
Horizontal μ_x	27 deg.
Vertical μ_z	94 deg.
Dispersion	0.8 m

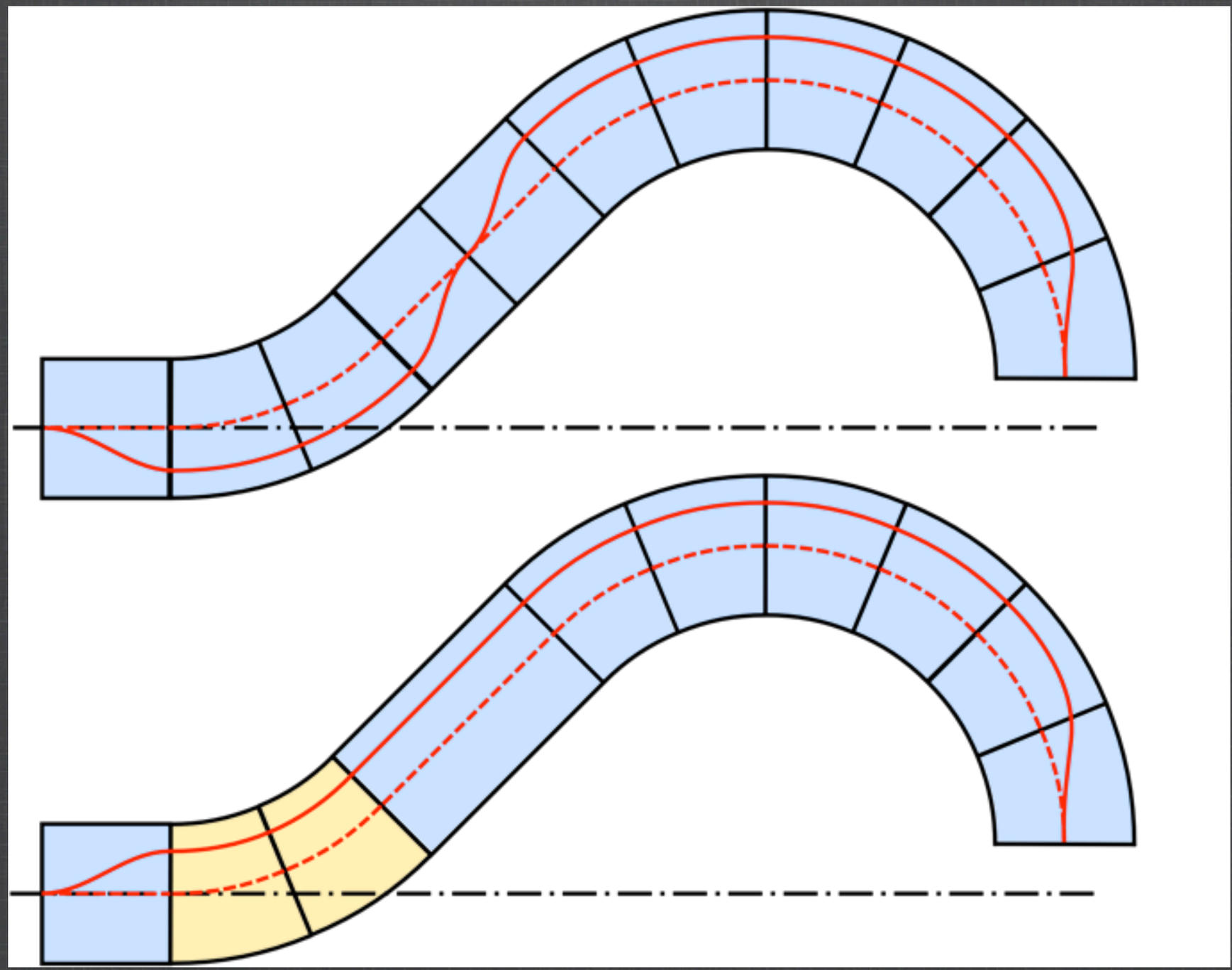
Applications

Another solution?



Applications

Gantry

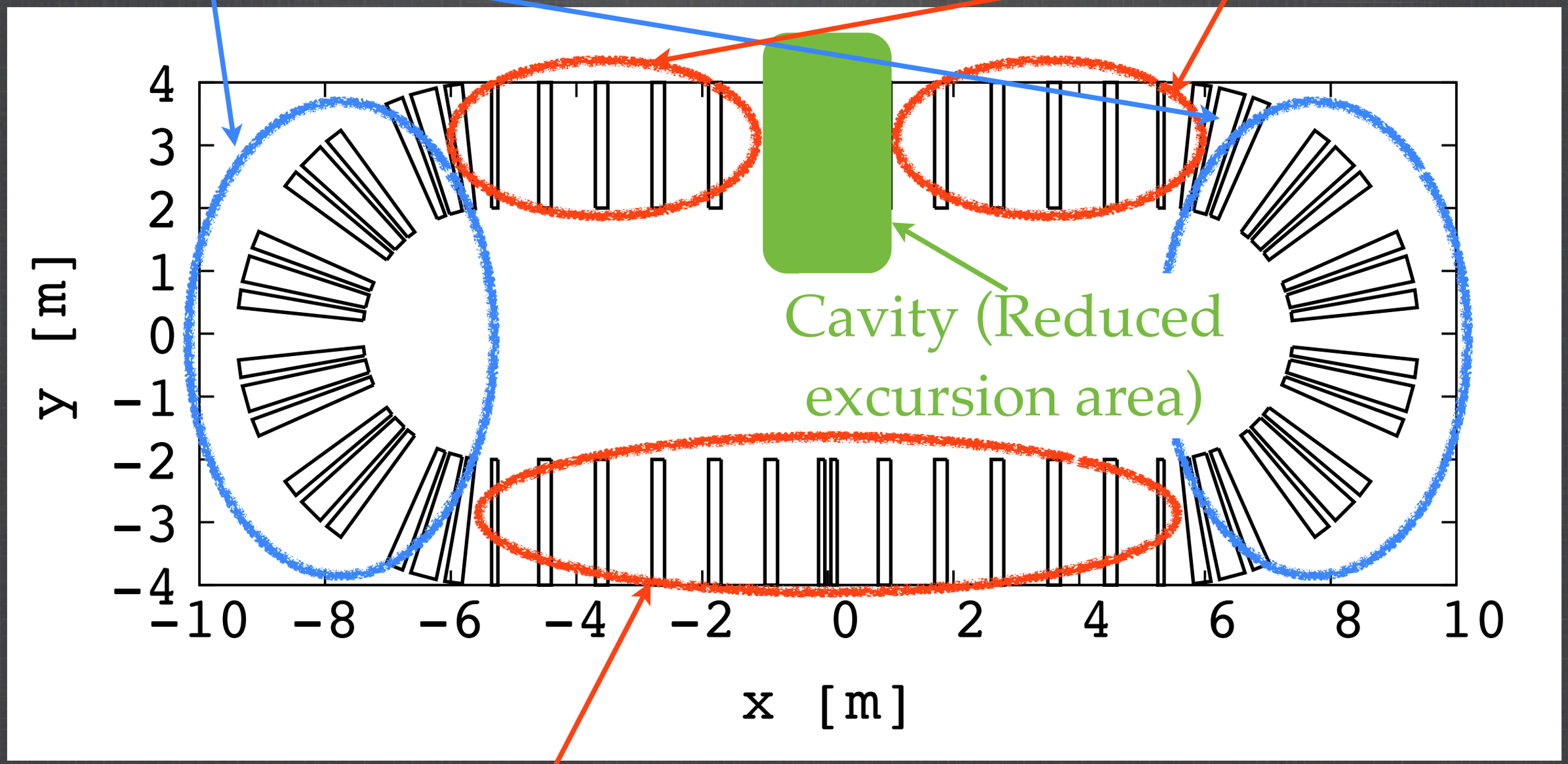


Applications

General Principle

Ring part
$B \alpha r^k$

Dispersion suppressor



Straight section: Injection - Extraction
$B \alpha e^{mx}$

Summary

- New tools have been recently developed to introduce more flexibility of the scaling FFAG.
- Experiments are under progress to study some of these new tools.
- This is only the start!

Thank you for your attention