KURRI Experiment Planning Session

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Why?

- Why would you choose an FFAG over a synchrotron or cyclotron?
  - It might be smaller or cheaper
  - It might have better performance
  - It might be able to perform in ways that are not possible with other machines (energy range, repetition rate, high power capability, reliability)
- What kind of applications might use these features?
  - Industrial accelerators:
    - irradiation, security scanning, isotope production
    - ADSR
    - others?

Why?

- Chao & Tigner handbook (2006) overview of FFAGs:

  "Fixed magnetic fields lead to spiral orbits, so an FFAGs vacuum chamber, magnets and rf cavities tend to be larger and more costly than a synchrotron's. On the other hand, its beam intensity can be much higher, as the radial and momentum acceptances are larger, and the repetition rate, set purely by rf consideration, can be several kHz"

  FFAGs have not yet demonstrated:

  1. High bunch charge capability
  2. The fundamental limitations of FFAGs with high current beams
  3. High repetition rates in the kHz range or CW beams
  4. Better reliability than a synchrotron

  In these experiments, we can potentially start to address (1) and (2).

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Which questions should we be asking?

(Based on our Cyclotrons 13 paper):

Q1. Do FFAGs face the same challenges in terms of space charge tune shift as synchrotrons?

- Do the denser resonance lines limit the maximum tune shift/spread more than in a synchrotron?

Q2. Can we maintain a large beam size to aperture ratio to accommodate more particles (taking advantage of the large acceptance)?

- How much coupling exists between horizontal and vertical planes?

Q3. Does beam intensity affect ionisation cooling?

Q4. Do current simulation codes (SIMPSONS, OPAL) predict the basic machine properties correctly? Do they predict high intensity behaviour correctly?

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Possible experiments

1. Initial setup and fixed energy measurements (For Q4)
2. Emittance growth with varying bunch charge - (For Q1)
3. Measurement of the transverse coupling - (For Q2)
4. Off-axis ‘painting’ injection - (For Q2)
5.

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1. Initial experimental work

Following on from Nov'13 visit...

- Implementation of new bunch monitor to enable real-time readout of horizontal and vertical position.
    - Re-calibration - how should this be done? Not sure we can just assume linear response of BPMs?
    - Map out horiz. position vs D current (ie. orbit movement) Q4
    - Tune measurement (vertical at least?) and compare to Nov'13 data Q4
    - Horizontal tune measurement with varying D current Q4
- Optimisation of injection setup using 2 BM & 2 small steerers (+ foil pos)
- Optimisation of COD correction strength with new corrector
    - + re-do emittance measurement (with scraper)? Q4
    - Position measurements (bunch monitor & with scraper) Q4

2. Emittance growth due to foil & with varying bunch charge

(Extending the idea of Uesugi-san's FFAG13 presentation):
- Constant RF frequency to avoid any acceleration emittance growth effects
- Chop injection beam and match with RF bucket
- Restrict vertical aperture with a probe and measure the time to lose the beam (ie. signal to zero) vs aperture height.
- Repeat for different bunch charge and/or painting (Exp. 4)

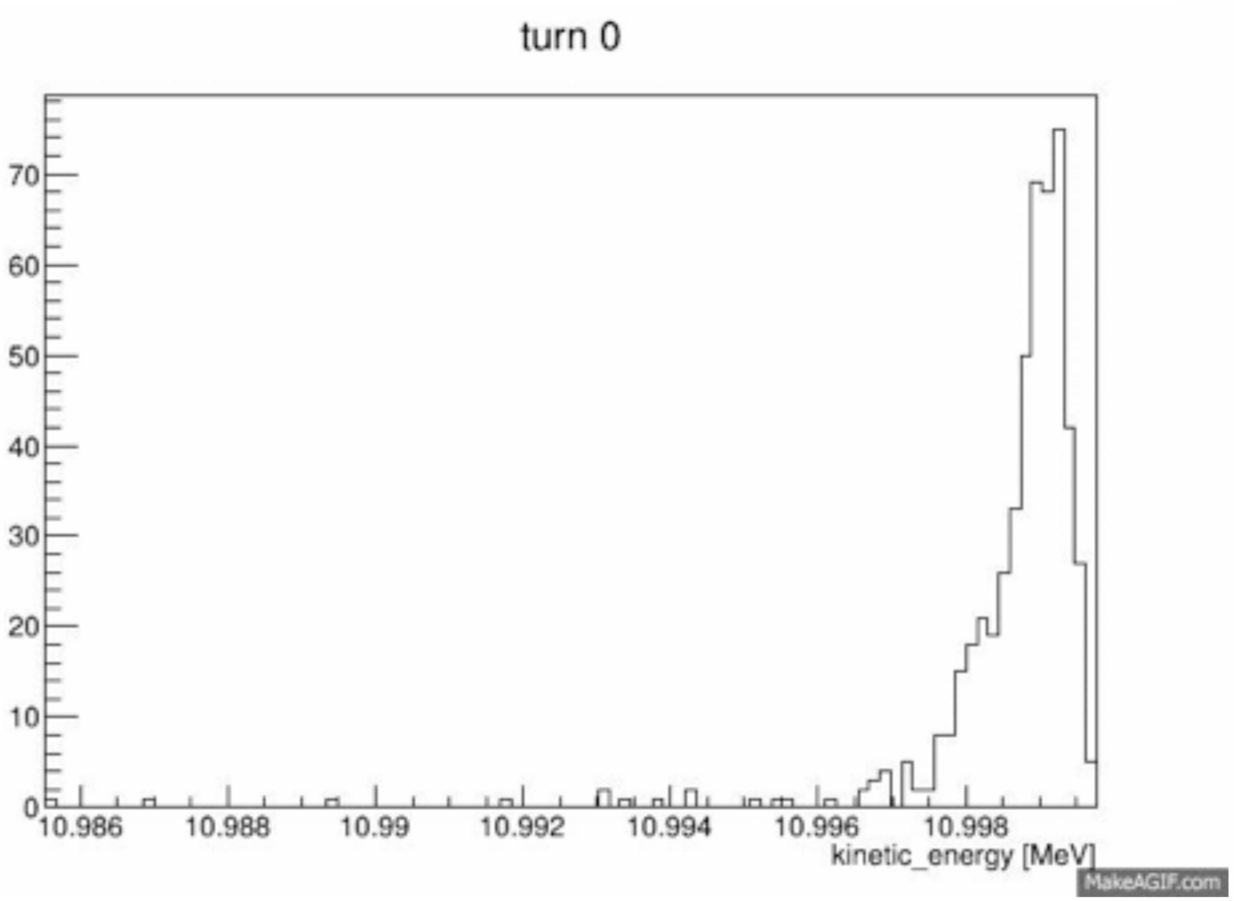
Q. How many particles can be injected?

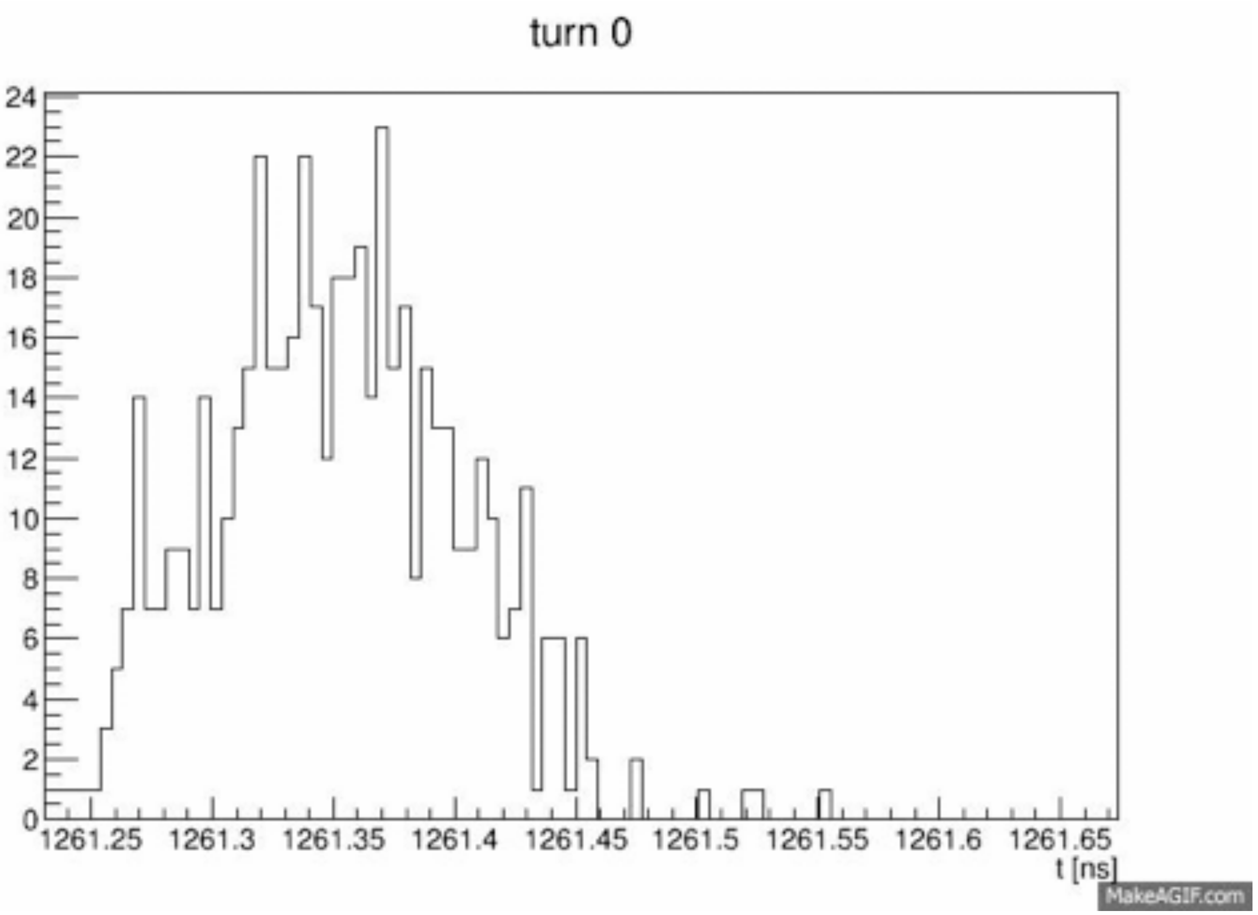
Current transformer measurement of current in injection line:
1mA x 30microsec = 20E+10 particles
nb. Revolution period = 660ns

http://hadron.kek.jp/FFAG/colabo/referencesformarch2014/FFAG13_uesugi.pdf

2. Emittance growth with varying bunch charge

Chris R's foil energy loss simulation results:
20 microgram foil, 1000 events



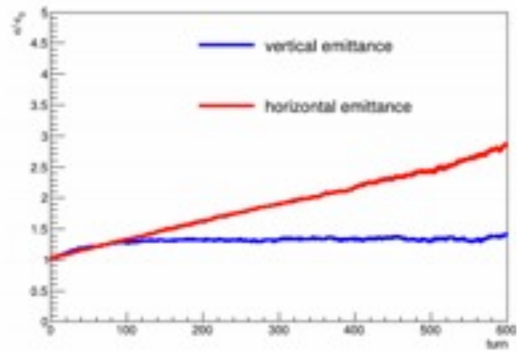


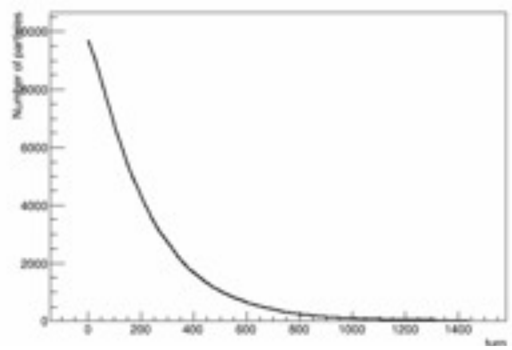
Energy loss quoted in presentations is 760eV/turn from Bethe formula
After 90 turns central E = 10.94 MeV so this translates to ~ 670eV/turn

2. Emittance growth with varying bunch charge

Transmission and emittances

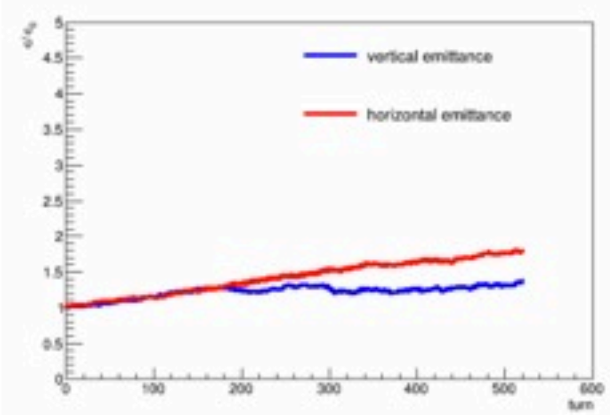
- Look at effect of foil on beam emittance
  - No RF
  - Inject 8 micron geometric emittance
  - Lose 50% of beam in first 200 turns
  - Injection cycle is ~ 160 – 1200 turns
    - (Uesugi, FFAG 13, slide 8)
- Is 15 mm real aperture?
  - Or just edge of field map...

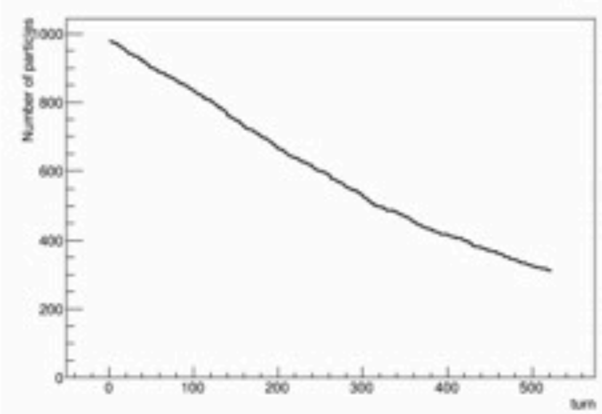




10e-6 g/cm² thickness

- For a 10e-6 g/cm² foil
  - No RF
  - Inject 8 micron geometric emittance
  - Lose 50% of beam in around 300 turns





http://hadron.kek.jp/FFAG/colabo/meetings/rogers20131024.pdf

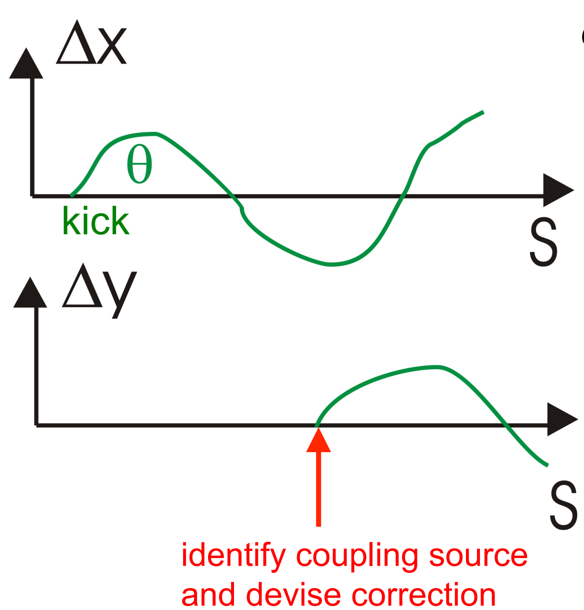
3. Measure the transverse coupling

1. 'First turn' analysis:

    - Large coupling sources are locations where a horizontal orbit change generates a vertical kick and vice versa. Method:

        Change orbit in one plane (by exciting steering correctors or by changing injection conditions).

        Measure the effect on the orbit in the other plane.



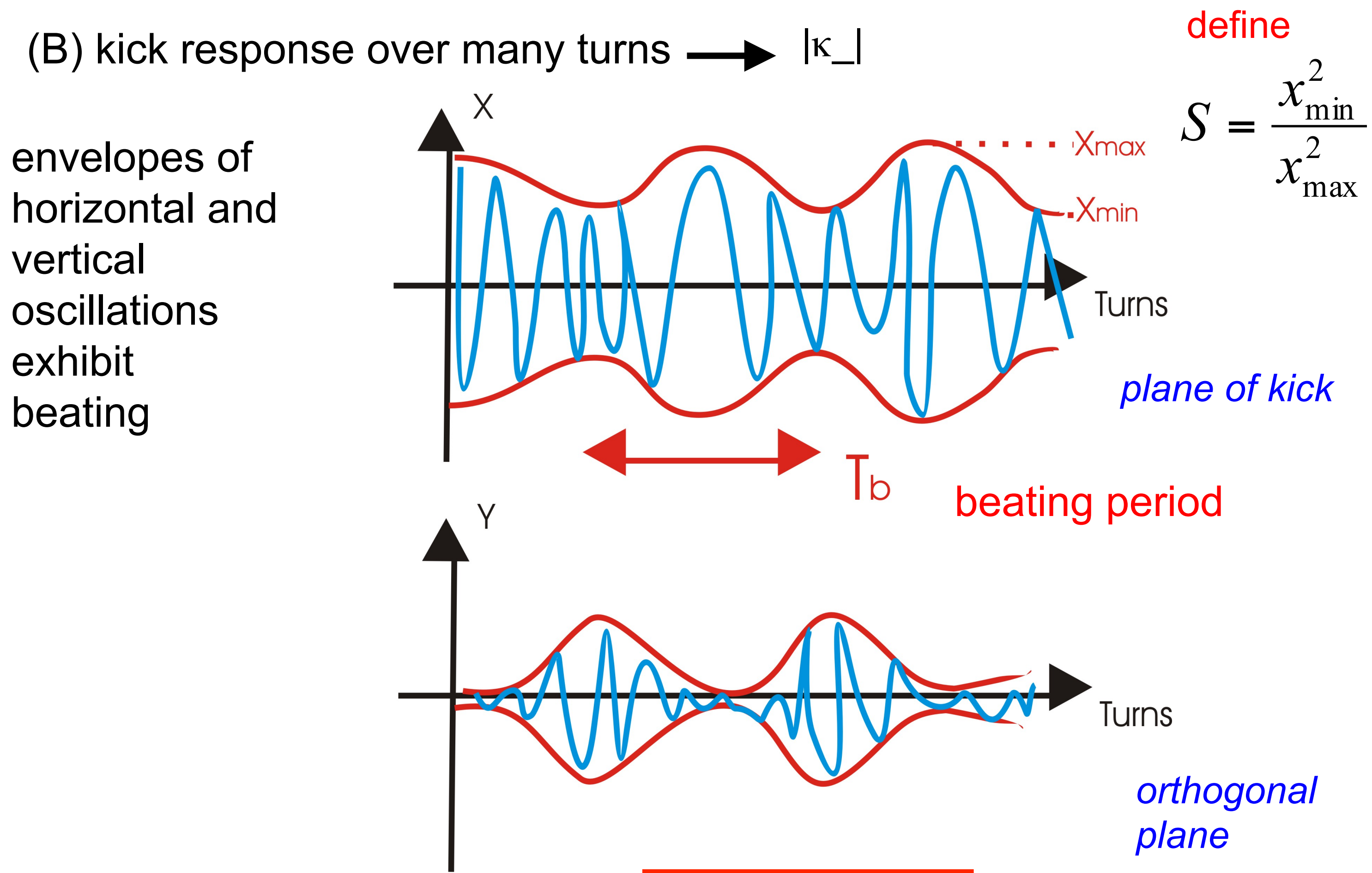
difference orbits

Normally this is done with many correctors and many BPMs to map out response matrix (and then corrected), but we are limited in the scope of what we can do here.

F. Zimmerman, SLAC-PUB-7844, 1998.
http://slac.stanford.edu/cgi-wrap/getdoc/slac-pub-7844.pdf

3. Measure the transverse coupling

2. Kick response over many turns



one can show that

$$|\kappa_-| = \frac{\sqrt{1-S}}{f_{rev}T_b}$$

!

example ATF

F. Zimmerman, SLAC-PUB-7844, 1998.
http://slac.stanford.edu/cgi-wrap/getdoc/slac-pub-7844.pdf

3. Measure the transverse coupling

Questions:

- If we do measure the coupling, can we correct it at all?
- If there is a large amount of coupling, does this rule out the use of large horizontal emittance beams to reduce space charge effects?

Further thoughts...

- Which foil thickness do we want to use? We may not be able to change it mid-experimental run.
- Will re-producibility of setup be good enough to ensure new injection/ COD correction settings will be effective for experiments?

Going forward...

- Which experiments should we do?
- Perhaps we should combine our experiment proposals in a table and rank them based on:
    - priority (scientific)
    - estimated chance of success
        - (this might need further elaboration of experimental details and some input from the KURRI team)
- We could also have a second list of 'future' experiment ideas or those requiring additional equipment