(Preliminary!) Plan for March Experiments at KURRI

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12/2/2014

I've tried to combine our thoughts... !
Some refinement is probably needed...

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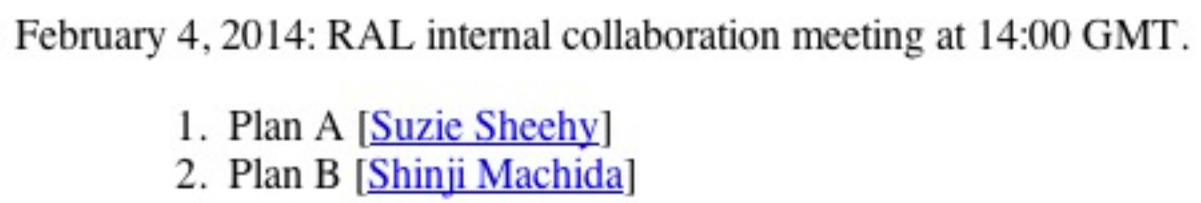
??

Original slides are on hadron.kek server:


February 4, 2014: RAL internal collaboration meeting at 14:00 GMT.

1. Plan A [Suzie Sheehy]
2. Plan B [Shinji Machida]

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Why?

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).

In general, 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 experiment list

1. Initial setup and BPM calibration
2. Measurement of linac beam quality (dp/p)
3. Horizontal and vertical orbit matching
4. Horizontal and vertical optics matching (?)
5. Dispersion matching in horizontal
6. Optimum RF frequency w.r.t. beam momentum
7. Emittance growth by multiple scattering at the foil
8. Energy loss at the foil
9. Optimum phi_s
10. COD correction and measurement
11. Tune optimisation and measurement at fixed energy & during acceleration
12. Measurement of the transverse coupling - (For Q2)
13. Emittance growth with varying bunch charge - (For Q1)
14. Off-axis 'painting' injection - (For Q2)

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Exp 1. Initial setup and BPM calibration

Following on from Nov'13 visit...

- Implementation of new bunch monitor to enable real-time readout of horizontal and vertical position.
    - Calibration - how should this be done? Not sure we can just assume linear response of BPMs? (Chris R's modelling work may help here?)
    - Can we make some 'quick' measurements as part of this to check and make sure we understand the newly instrumented system?
        - Eg. Map out horiz. position vs D current (ie. orbit movement) , or make a tune measurement (vertical at least?) and compare to Nov'13 data?
    - Will this make the horizontal tune measurement with varying D current easier?

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Exp 2. Measurement of linac beam quality

Make the rest of the experiment easy if we know dp/p at least.

Spectrometer type measurement is already planned?

Relative rf phase among RFQ, DTL1 and DTL2 change dp/p.

How the injection efficiency change when phase is adjusted?

Stability, day to day, is also important factor.

F/D/COR	814/995/445
HMBT-ST	Normal values
RF	off
BMON	(INU), AMP
OSCILLO	AC-50 Ω, Obake-subtracted
CHOPPER	0.2% (0.316 revolutions)

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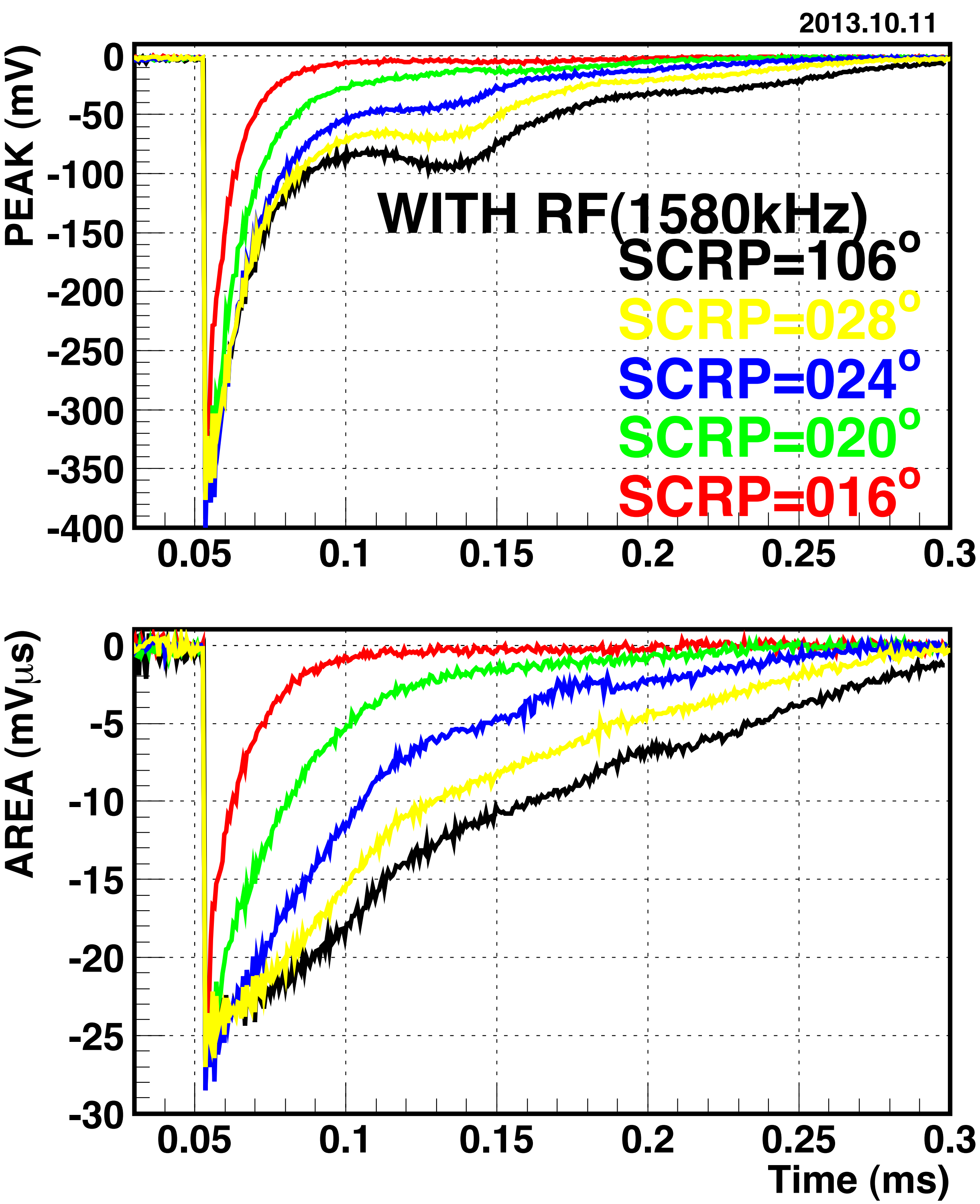
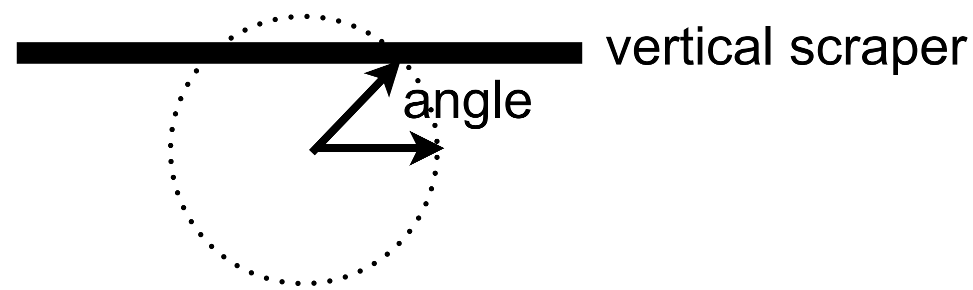
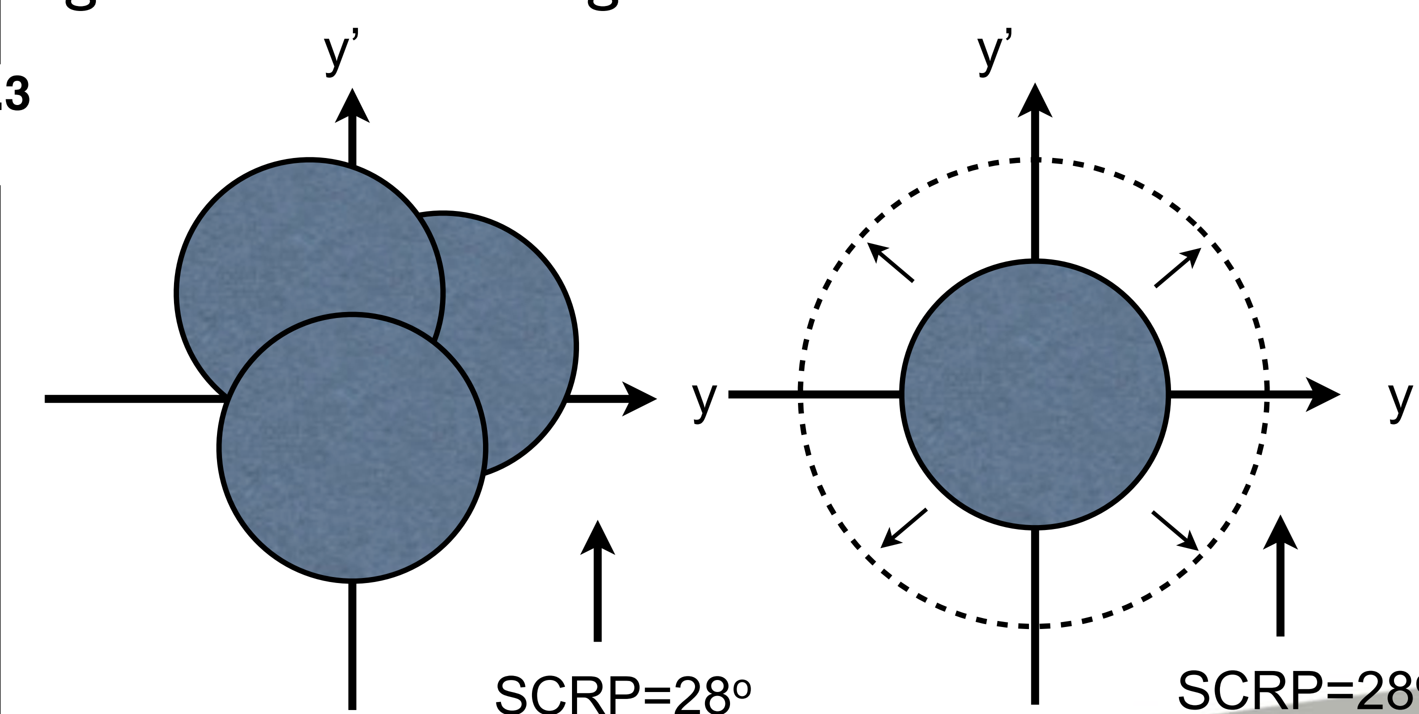
Vertical orbit matching (1)



Small aperture difference results in large difference in intensity.



Is this due to injection orbit mismatch instead of gradual emittance growth?



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Exp. 3: Vertical orbit matching

If the vertical coherent oscillation can be observed by the new system, tuning of orbit matching is easy.

If not, set the scraper around the beam edge and minimise beam loss.

Q: Which knobs are available to change *y* and *y'* at injection point?

We believe there are 2 vertical steerers (and 2 bending magnets) is that correct?

Exp. 4: Optics matching?

- This seems to be difficult to measure the twiss parameters etc in the linac & ring at the moment.
- There is some discussion in 'extra slides' later...

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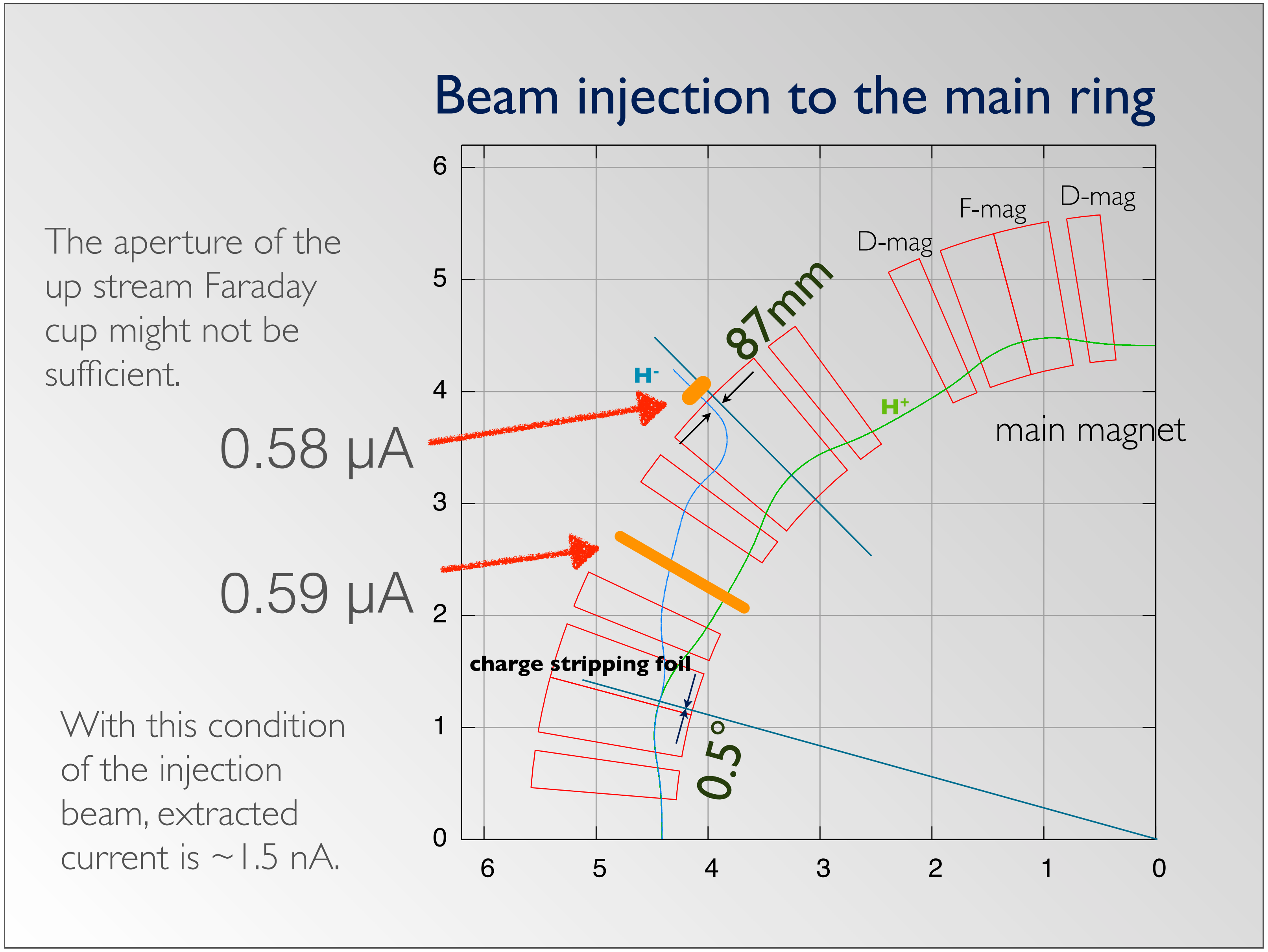
Exp. 5: Measurement of dispersion function@foil



Sunday, September 22, 13

If the position at foil can be measured (foil position which gives maximum H+),

1) change main magnet strength to change "equivalent momentum".
2) measure how much the beam position moves.

Issues: how do we measure this?
•We can measure position downstream but not at the foil itself.
•Shinji suggested a wire instead of the foil to measure horiz. profile.

Making a dispersion matching is tricky because higher momentum beam must bend more on average.

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Exp 6: Optimum rf frequency w.r.t. beam momentum

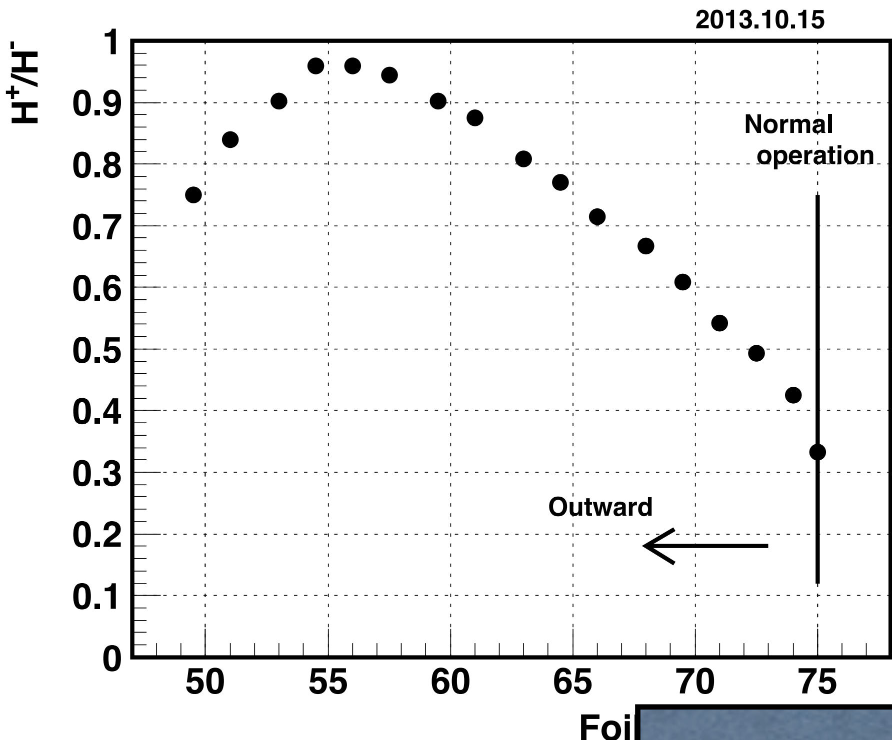
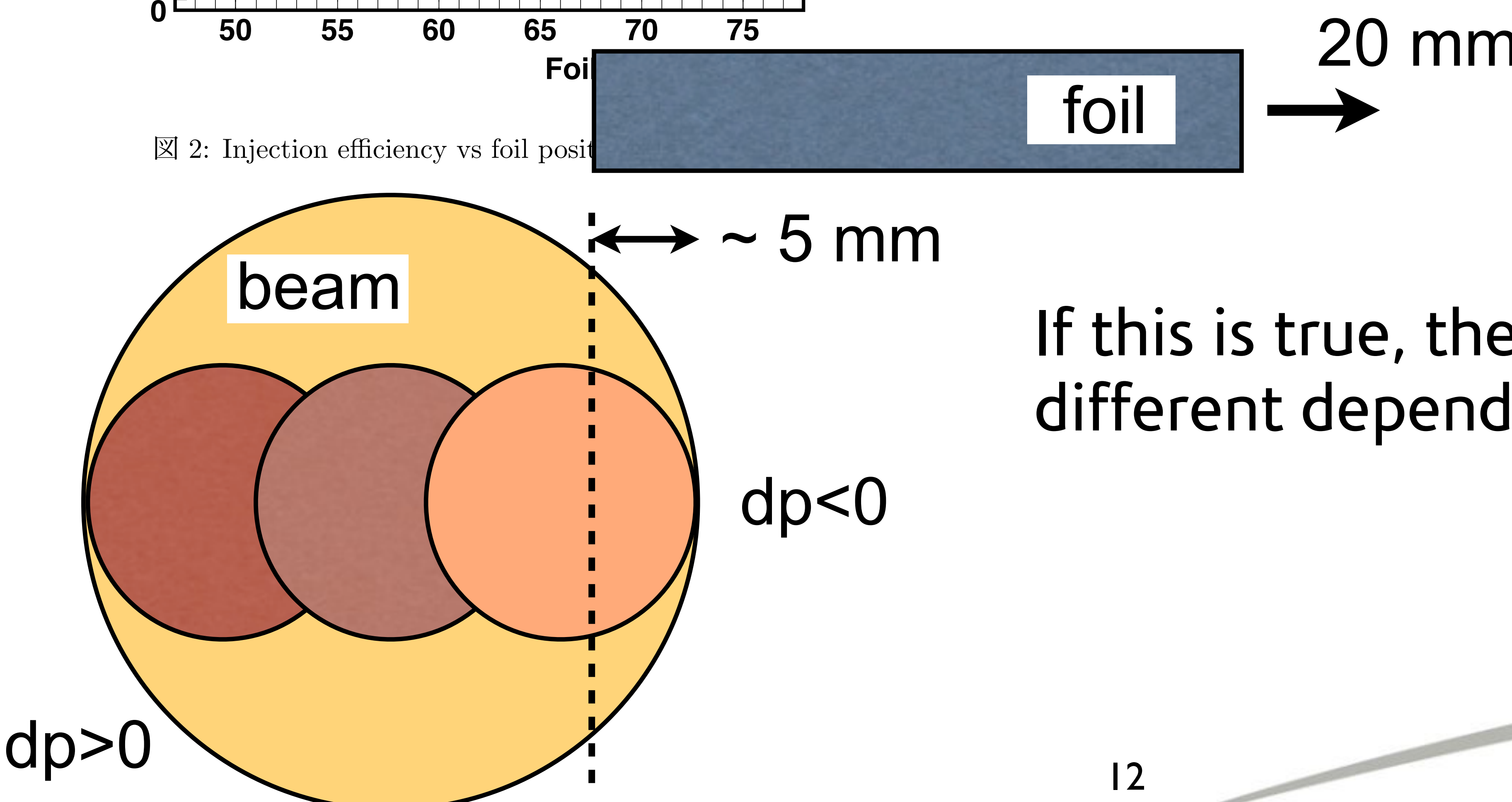


図 2: Injection efficiency vs foil posit

Move of 20 mm still give 30% beam can be another reason that beam is wide.

Injecting only one 'slice' of the beam may mean we do momentum selection (injecting relatively low momentum side).



If this is true, the optimum rf frequency is different depending on foil position.

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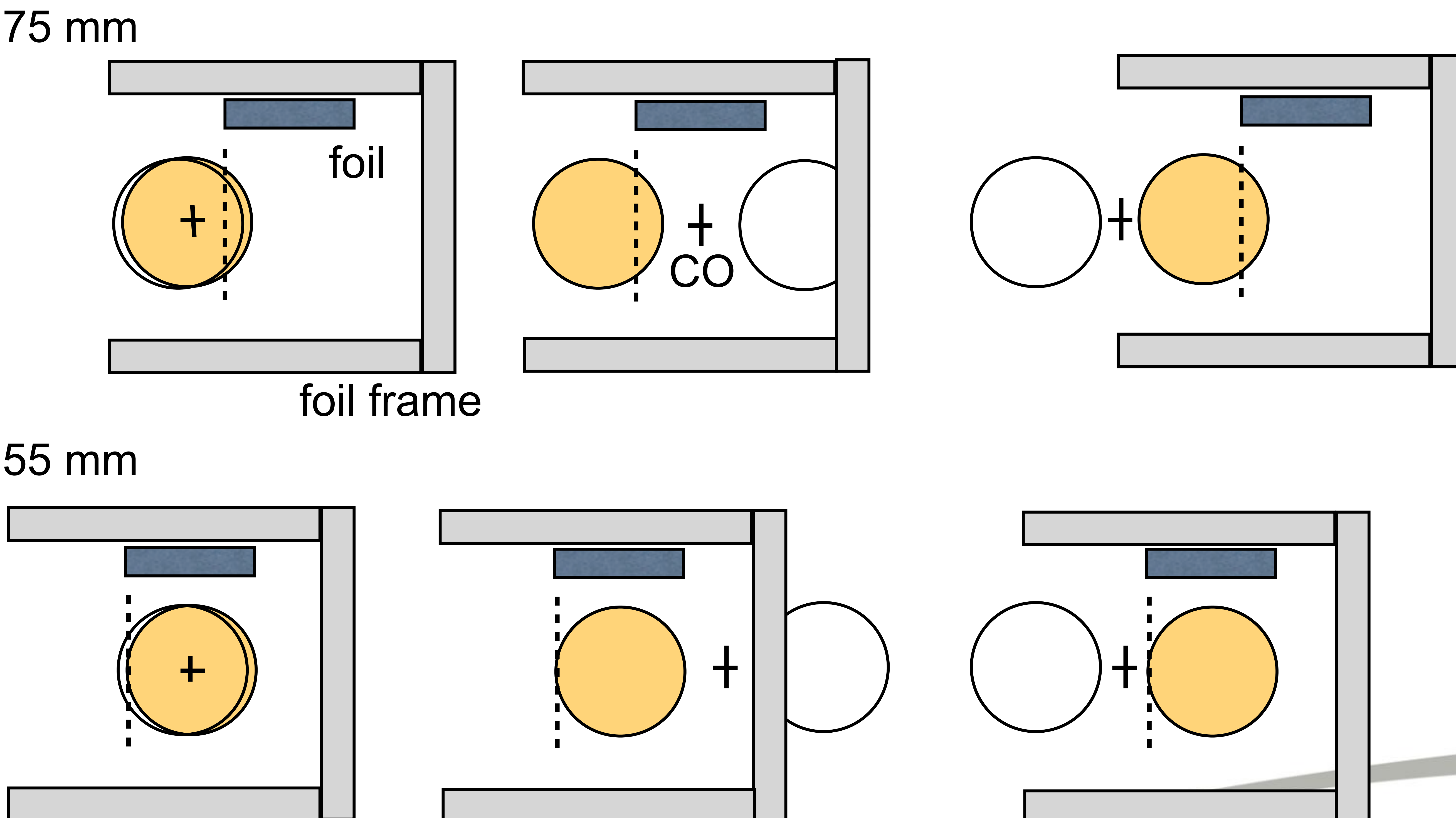
Measure the location of closed orbit



Measure CO at other places and translate.

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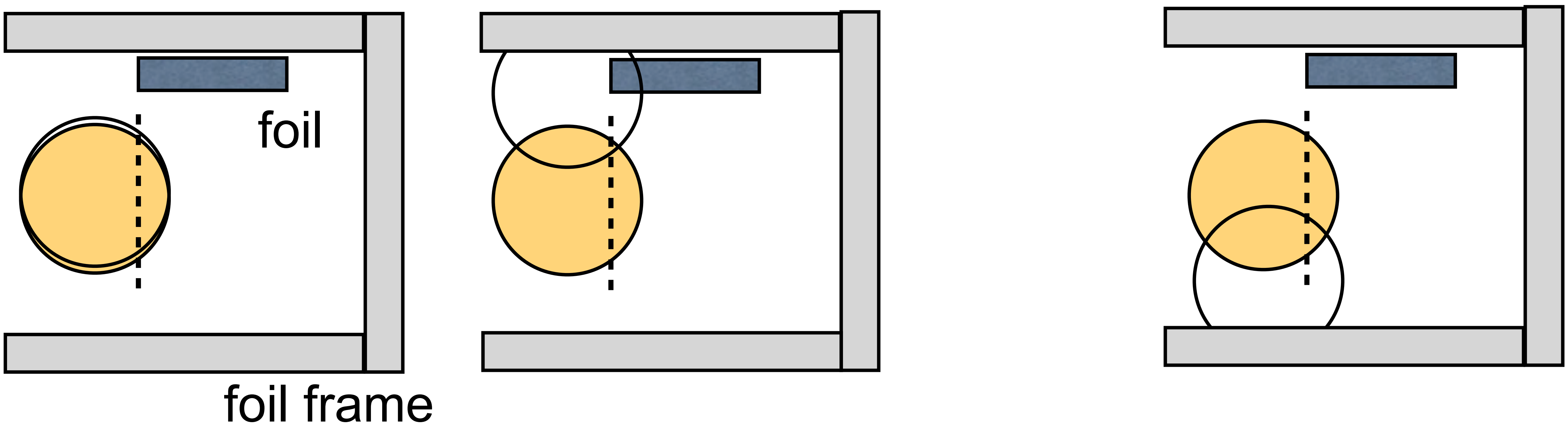
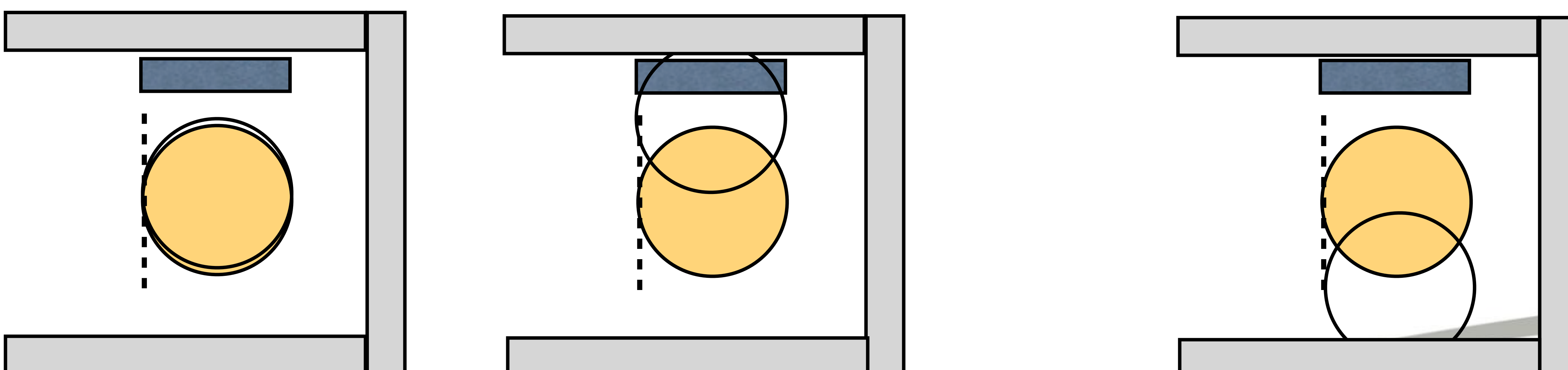
Same for vertical

75 mm



55 mm



Measure CO at other places and translate.

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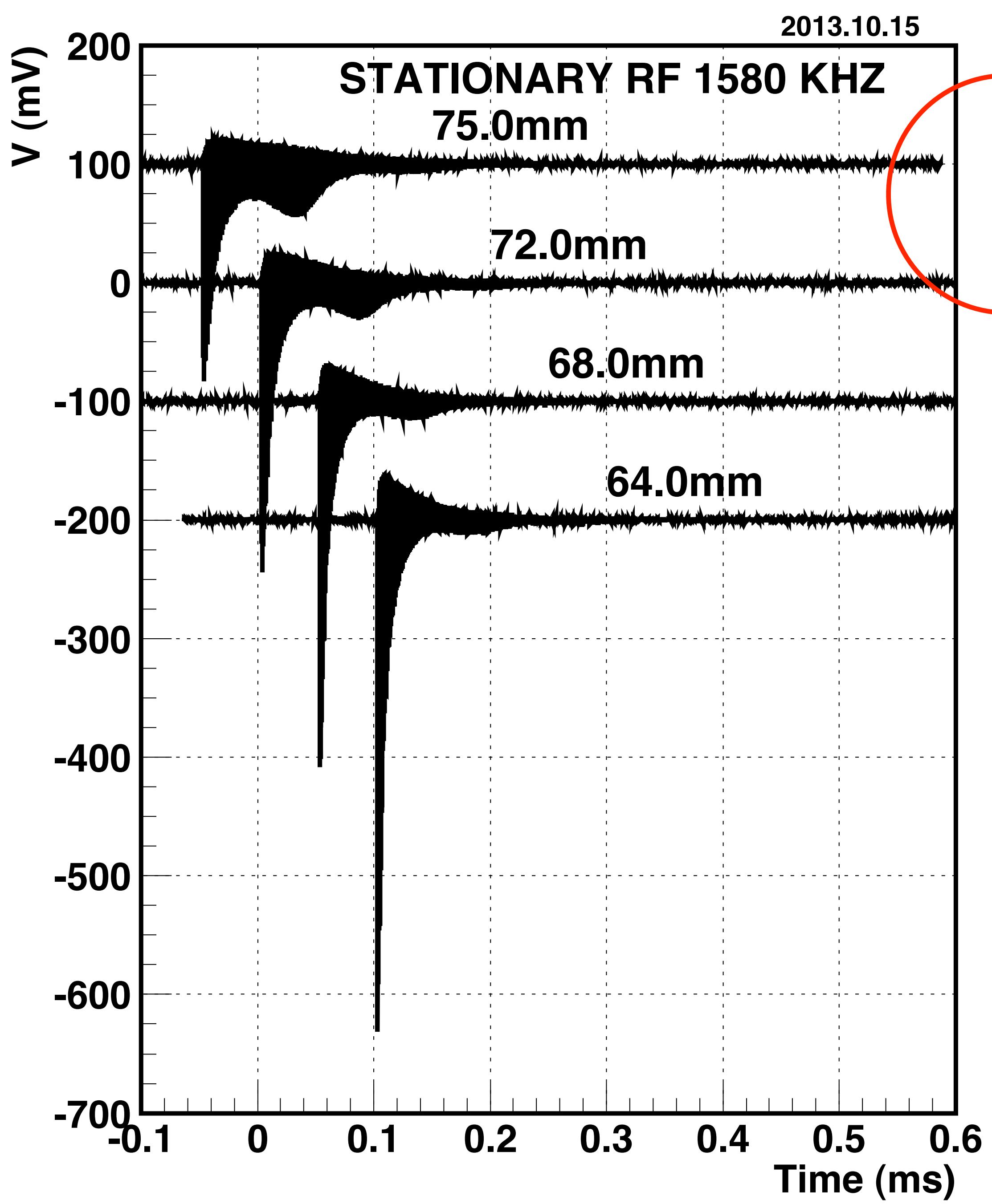
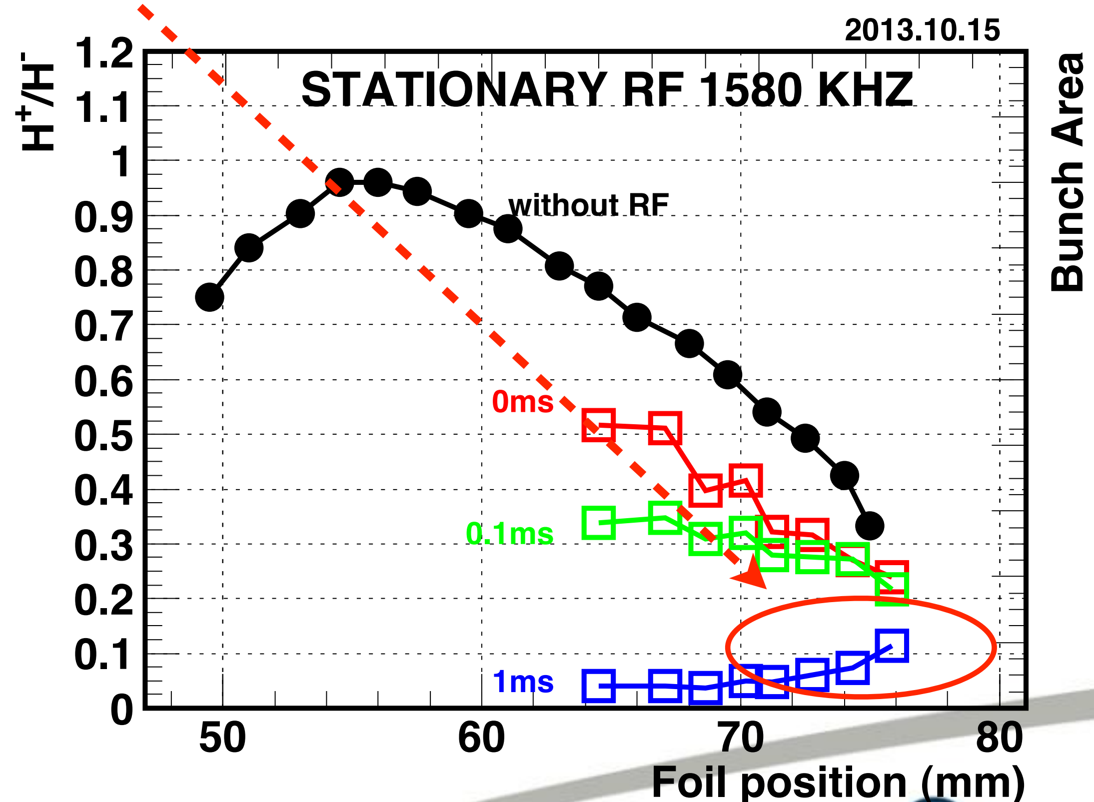
In stationary rf bucket



Need to know
1) where is the closed orbit,
2) amplitude of initial mismatch.

Is there any particles survive at 1 ms when foil is 72 to 75 mm?



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Emittance growth from scattering

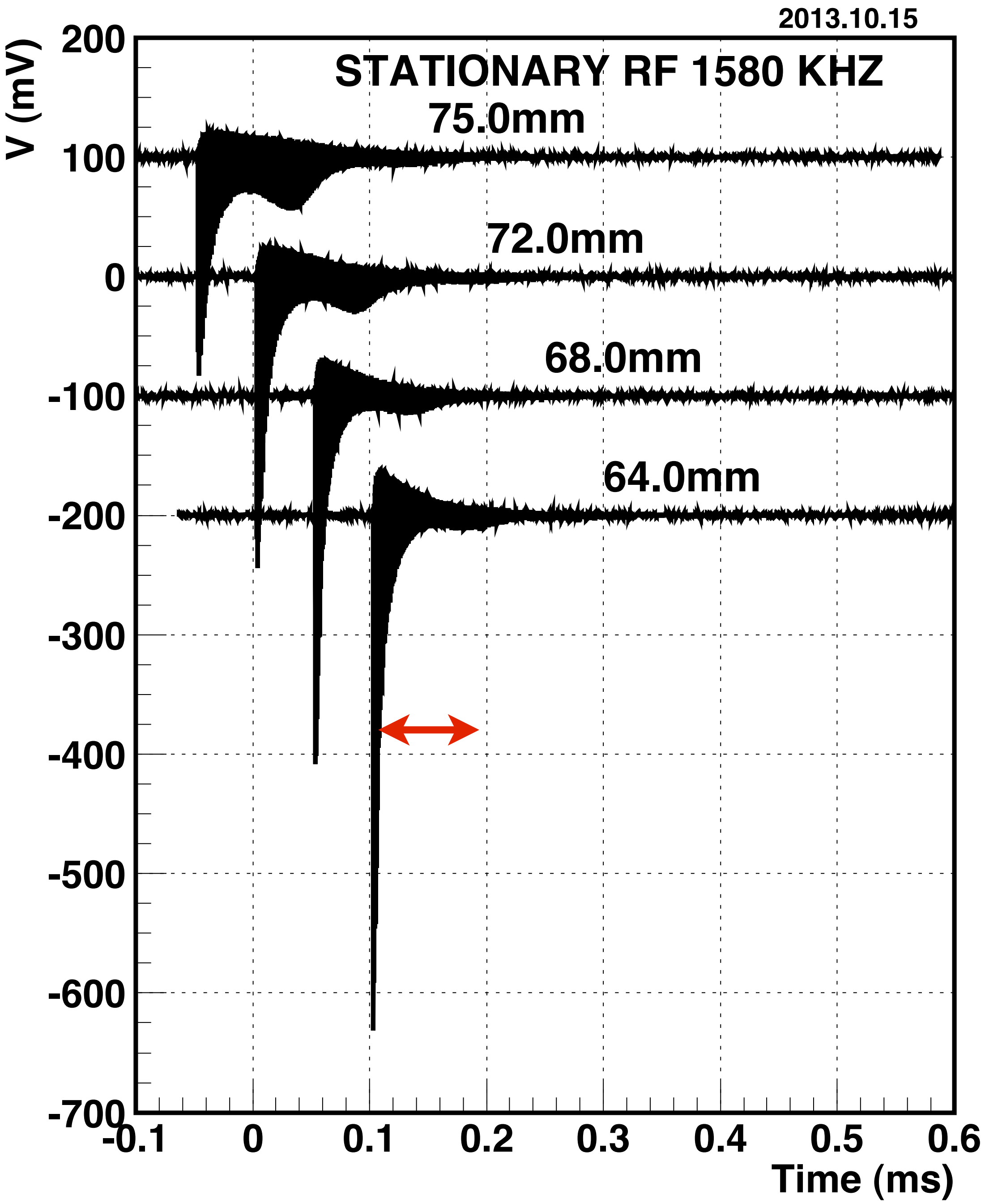
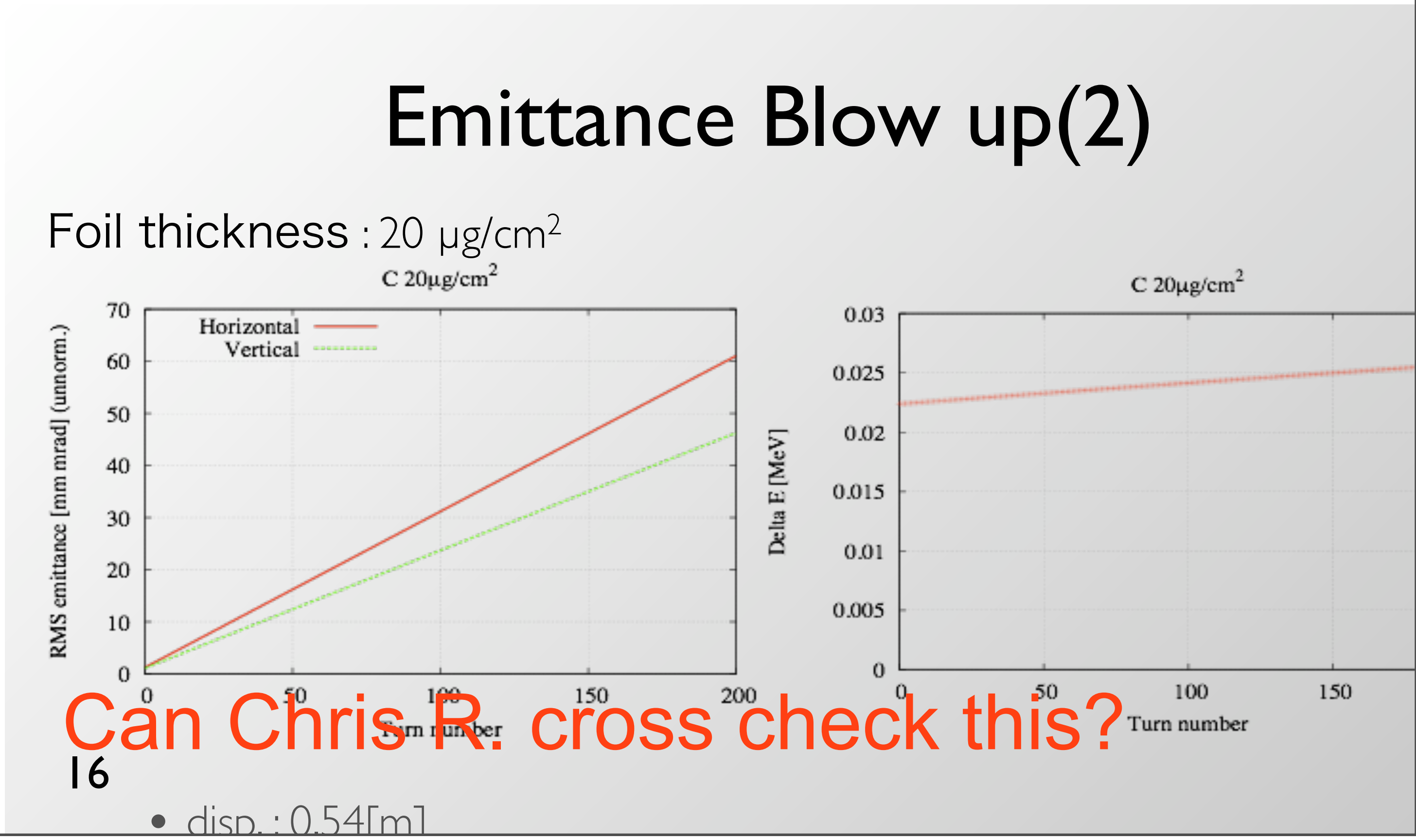


Figure shows considerable beam is lost in 0.05 to 0.1 ms. (78 to 156 turns)

From Okabe's slide at FFAG11, rms emittance (unnor.) becomes
~45 p mm mrad.

rms beam size becomes ~12 mm.



Can Chris R. cross check this?

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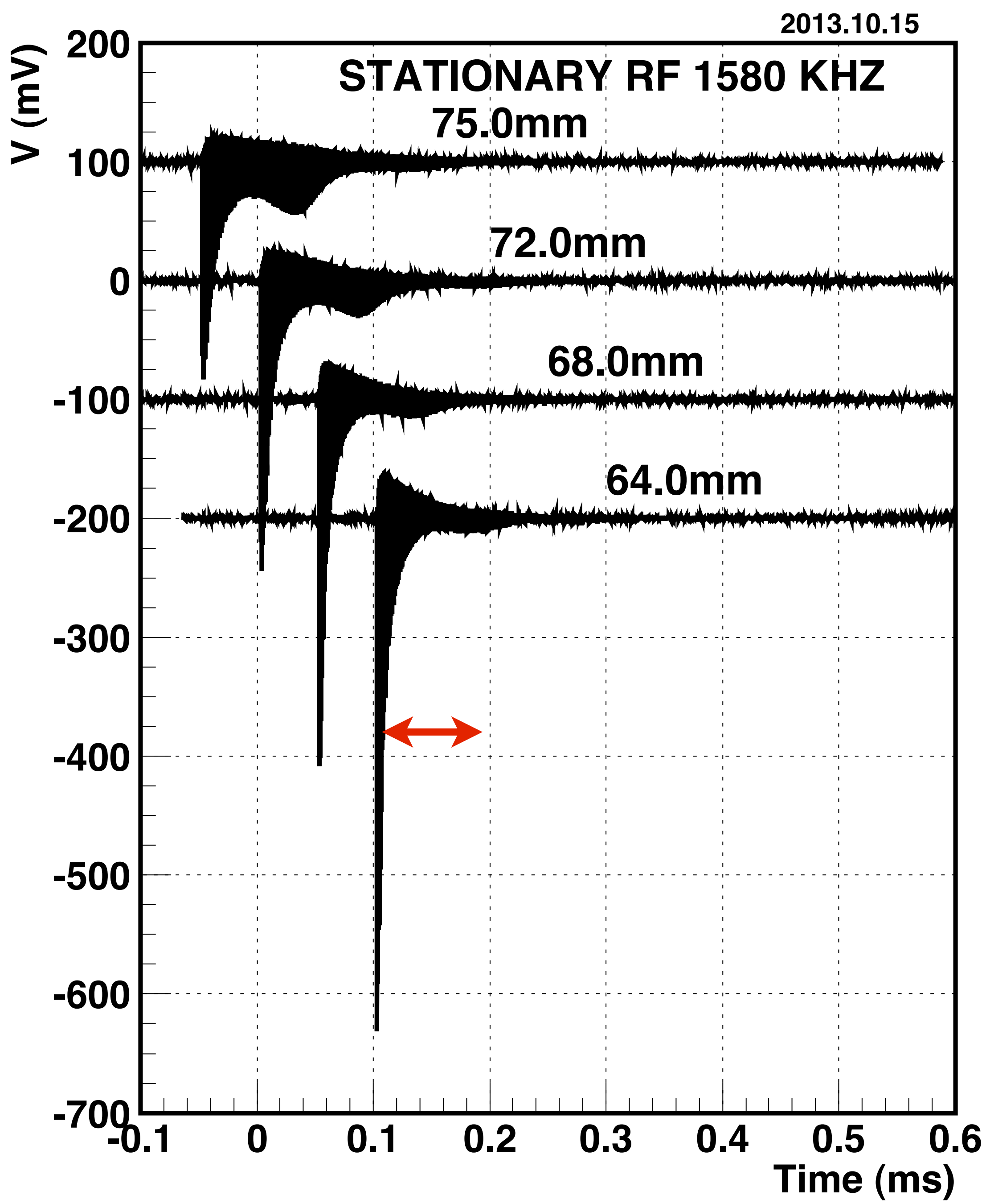
Empirical rule



Difference between 75 mm and 64 mm comes from hitting probability (FP).

Assume FP~1 at 64 mm, then a condition which makes a beam survive is

FP x t < ~0.1 ms

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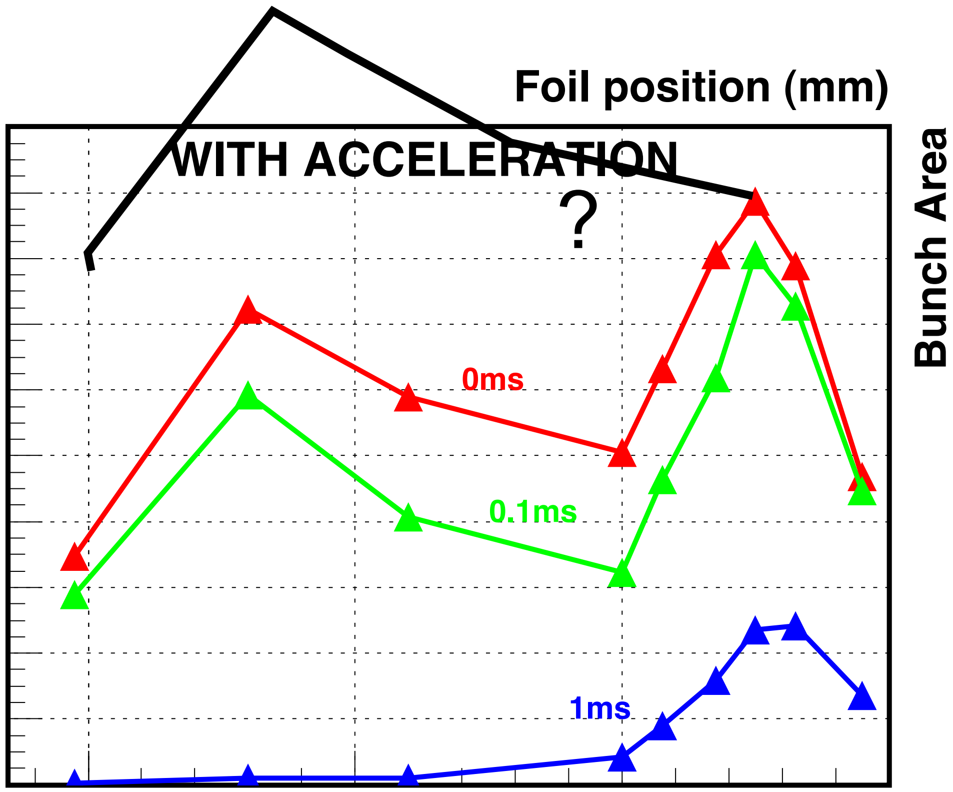
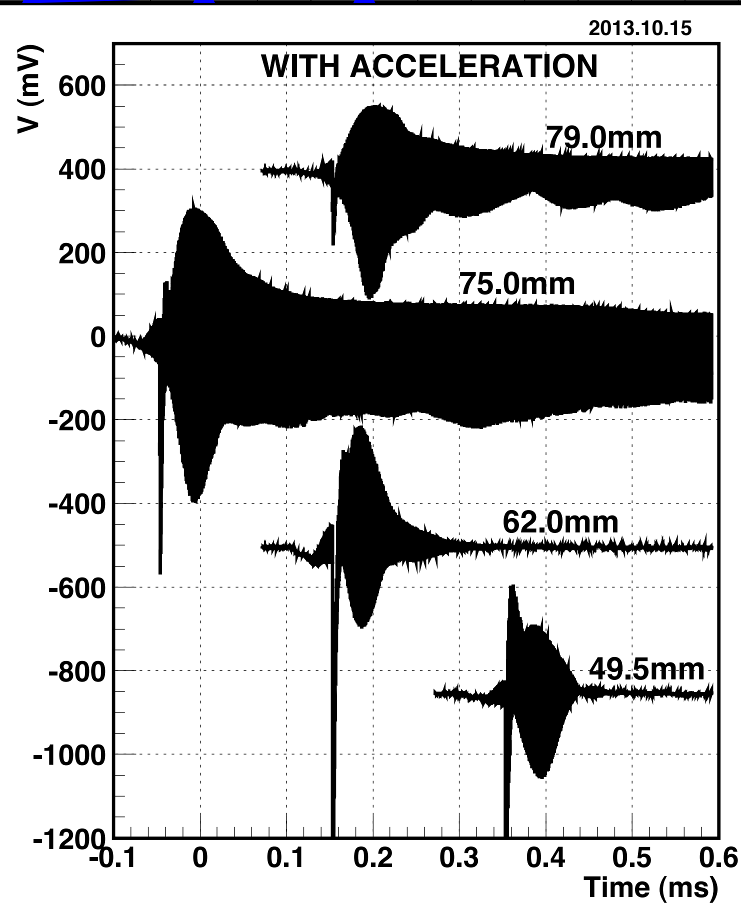
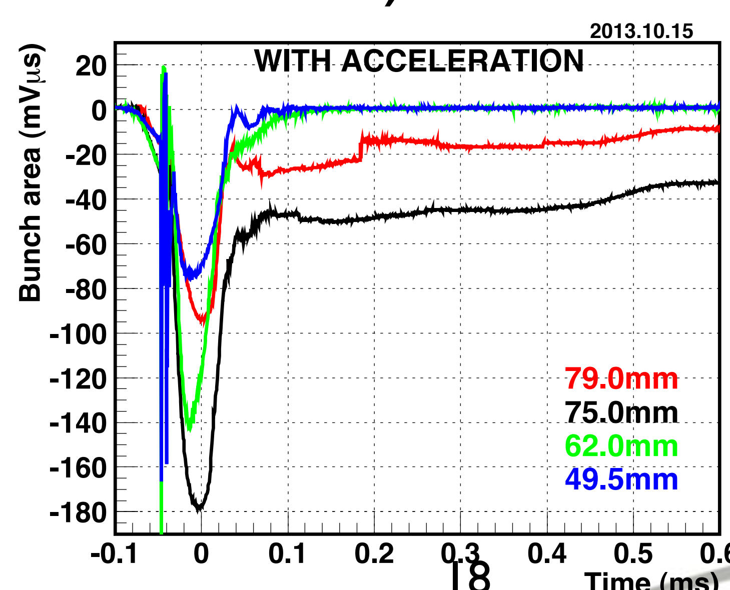
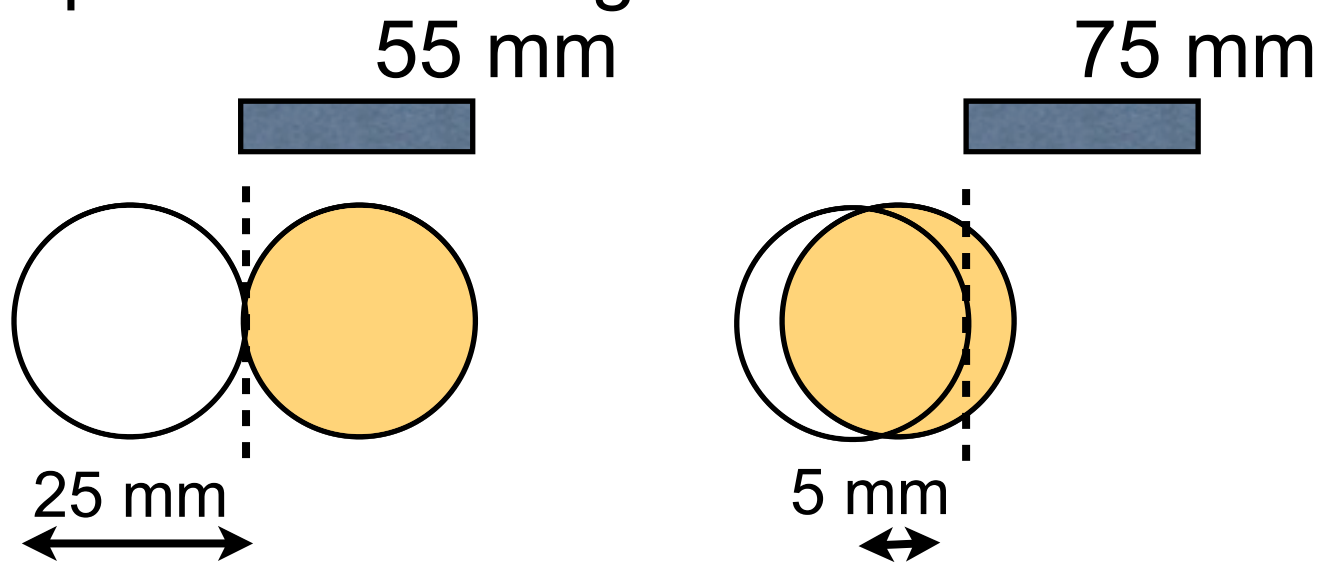
In moving rf bucket







Beam moves 6~7 mm in 0.1 ms
when phis=20~30 deg.



1) takes ~0.4 ms
to go out of foil.
2) FP ~ 1

1) takes <0.1 ms
to go out of foil.
2) FP < 1

FP x t < ~0.1 ms

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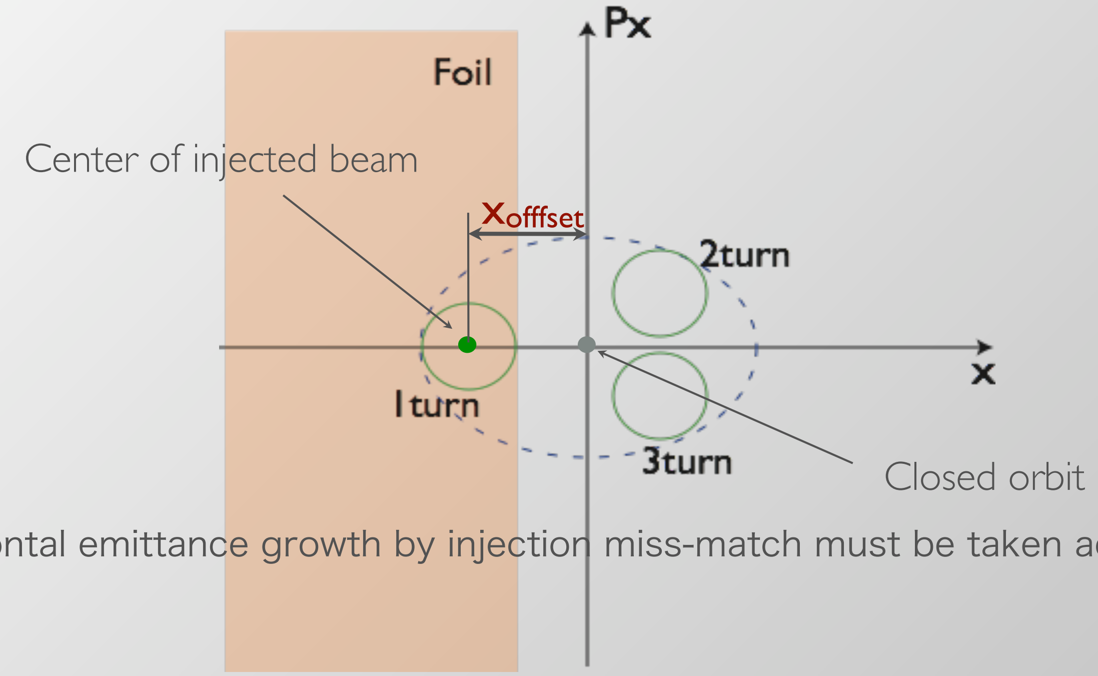
Exp. 7: Horizontal orbit mis-matching

Off-center Injection

Low energy injection(11MeV), circulated beam hit foil many times. Energy loss and emittance growth are become problem. To decrease the hitting probability, H- beam is injected off-center by about 10 mm parallel shift of injection line.



Horizontal emittance growth by injection miss-match must be taken account.

It is not clear if we should inject a beam on the closed orbit.

The horizontal BPM tells us the amplitude of mismatch and position of closed orbit.

Manipulate closed orbit@foil to decrease FP.

In practice, it may be difficult to shift the beam from closed orbit for more than a beam size. (if beam size is too big.)

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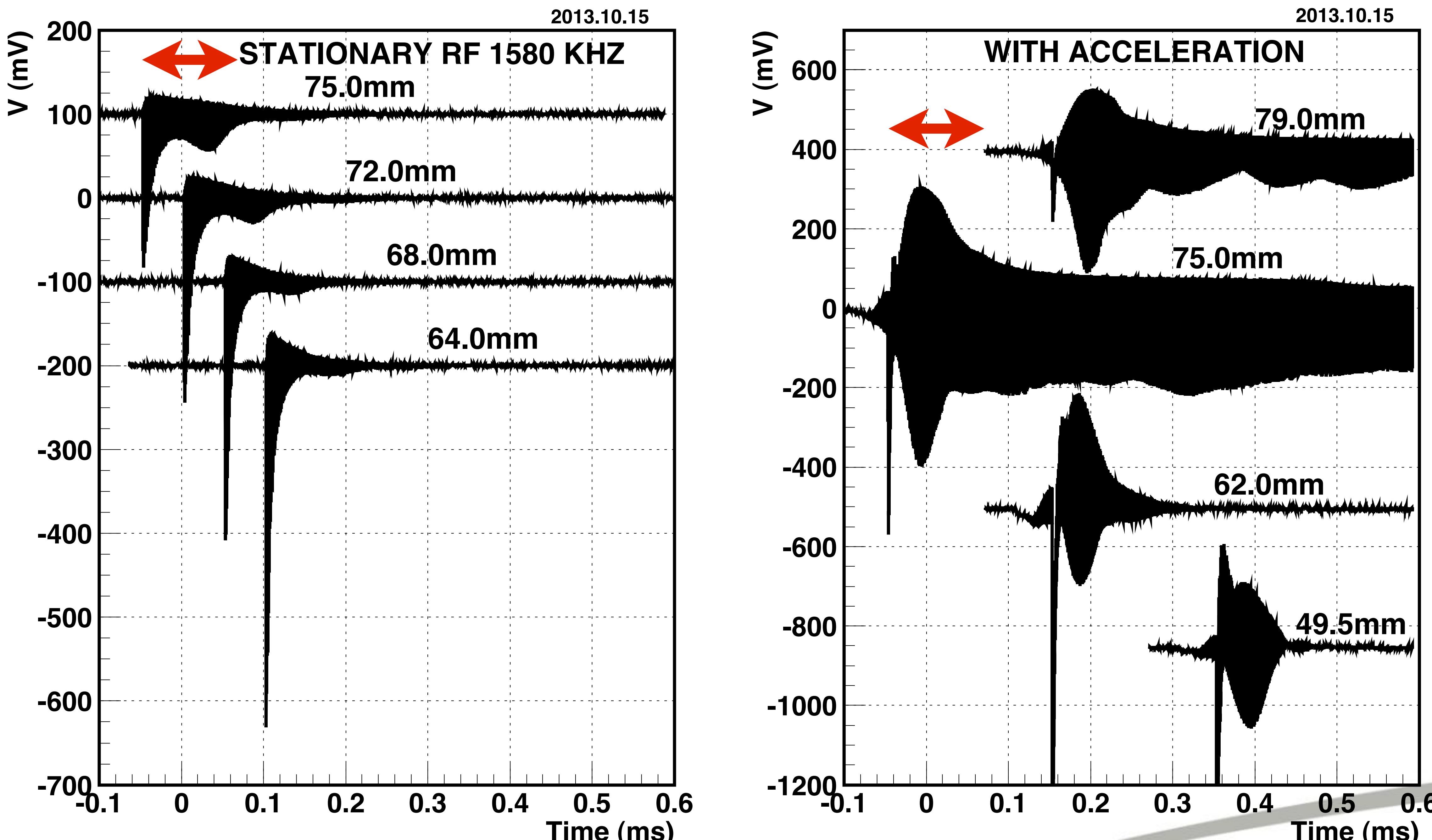
Can we repeat this after knowing COD position?



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Injection seems to be the biggest issue

- Injection of 2.56 us (= 0.640 x 4 turns)
  - survival after 1 ms is 1/30.
- Injection of 50 us (= 0.640 x 78 turns)
  - survival after 1 ms is 1/400.
  - only 1.5 times more than 4 turns injection.
- Still 1/400 seems worse than expected. May need to consider longitudinal (accumulated momentum spread) as well.

Once we have done the earlier experiments,
we can move onto the more precise ones...

Exp. 8: Energy loss at the foil

See Chris R's foil energy loss simulation results.

Exp. 9: Optimum phi_s

Exp. 10: COD correction & measurement

Exp. 11: Tune optimisation & measurement at fixed energy and during acceleration

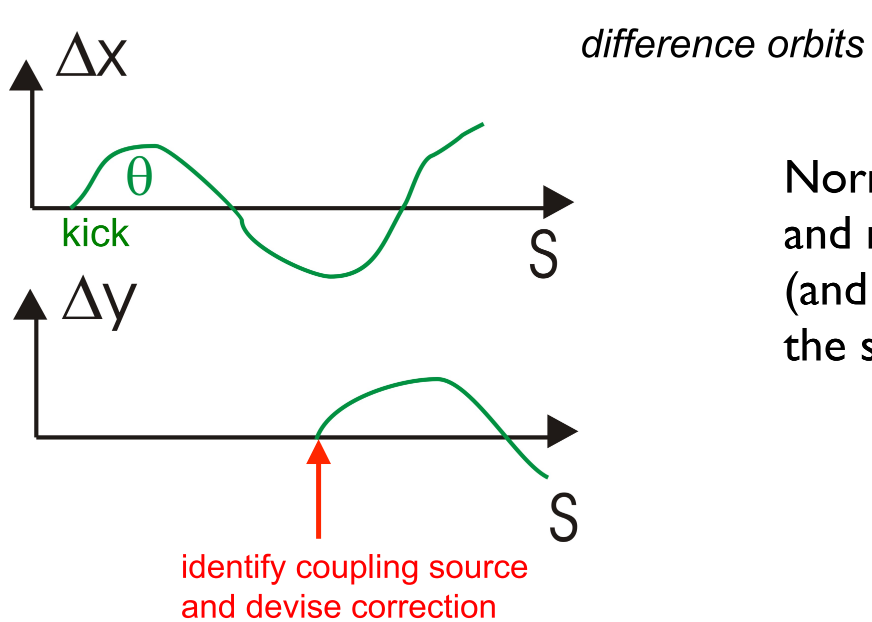
Exp. 12: Measure the transverse coupling

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.



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

Exp. 12: Measure the transverse coupling

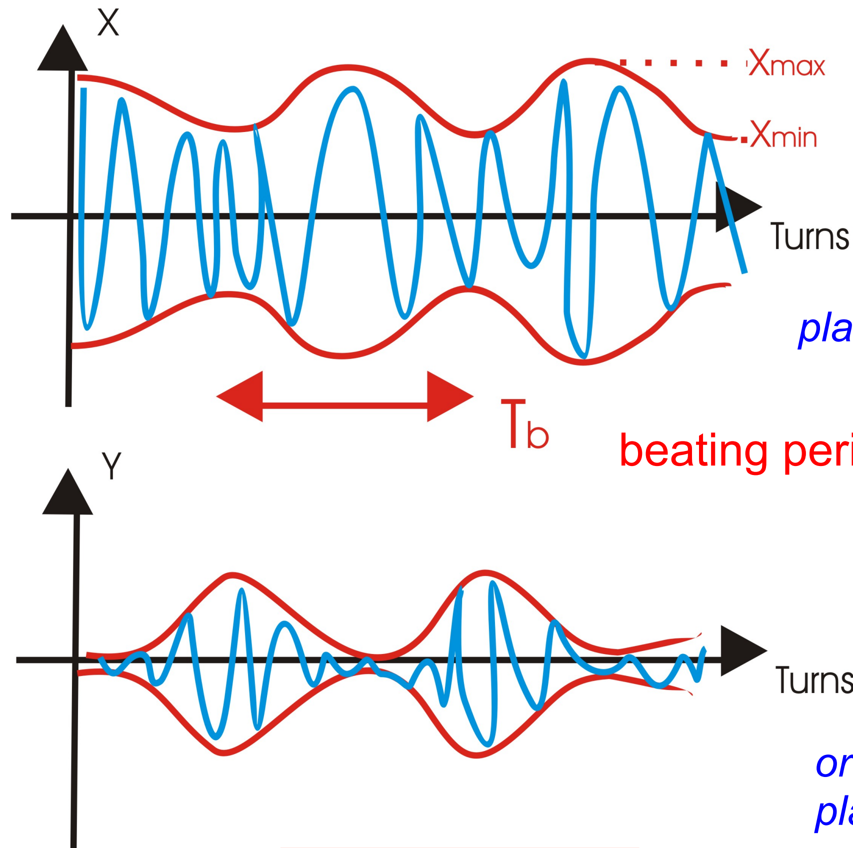
2. Kick response over many turns

(B) kick response over many turns → |κ_|

define

$$S = \frac{x_{\min}^2}{x_{\max}^2}$$

envelopes of horizontal and vertical oscillations exhibit beating



plane of kick

beating period

orthogonal plane

one can show that

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

example ATF

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

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Going forward...

- Please contribute more proposals if you have them!
- Many of the proposals are necessary in order to do more complex experiments successfully later on.
- I have started to combine the proposals in a spreadsheet to help gather the information together so everyone knows what is happening!
- The 'future' experiment proposals (including high intensity ones) might need to be ranked based on:
    - priority (scientific)
    - cost to implement (extra equipment etc)
    - estimated chance of success/risk involved
    - machine time required
        - (this might need further elaboration of experimental details and some input from the KURRI team)

Decisions to be made prior to March run:

- Which foil thickness will be used?
    - (Can it be changed quickly? My understanding is no)

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Additional Slides

Optics Matching Discussion

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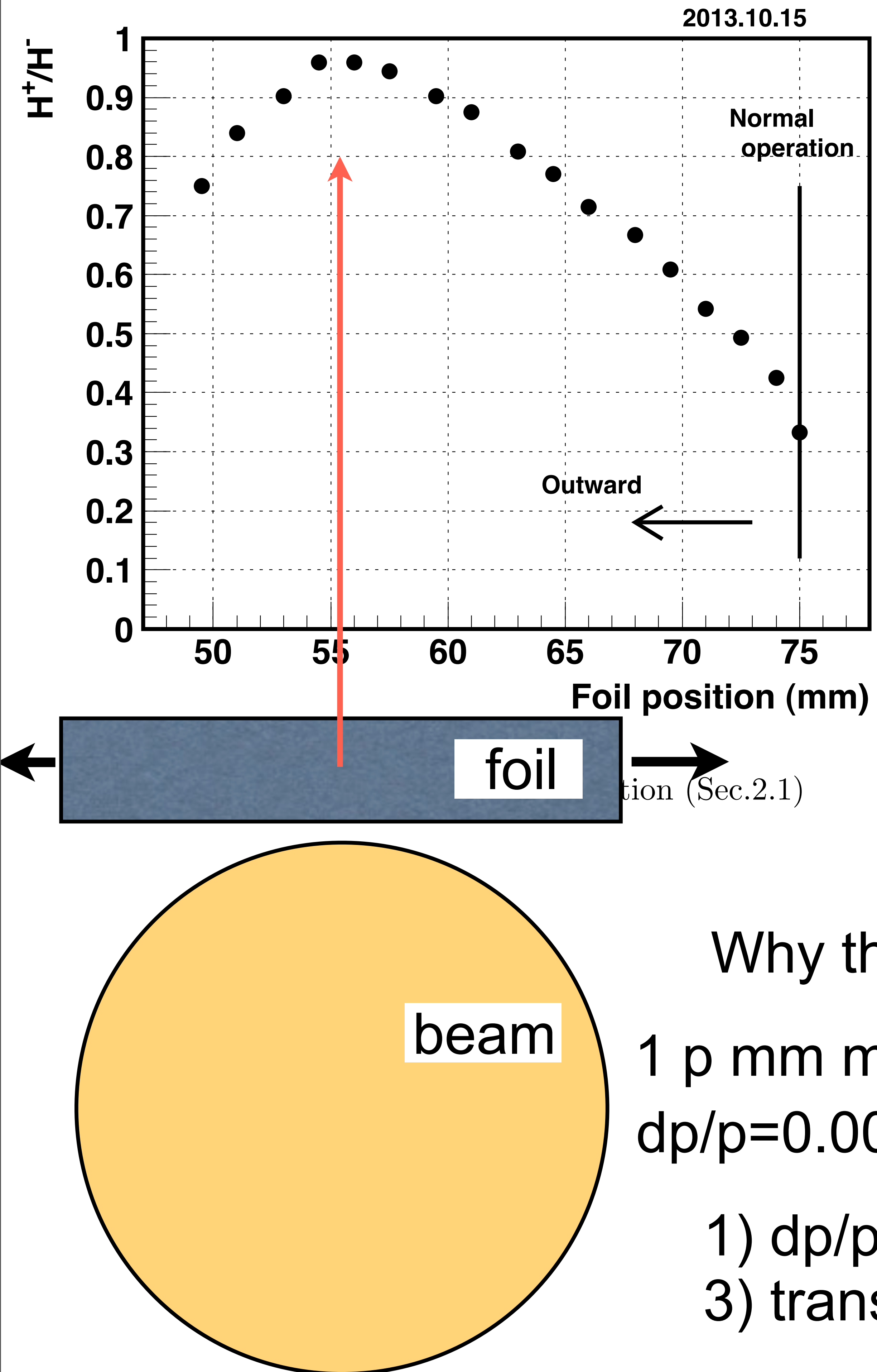
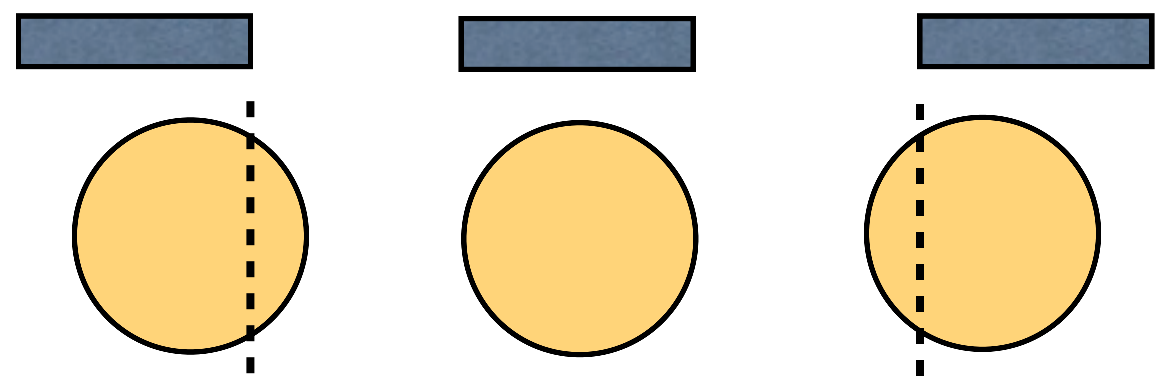
Horizontal beam size from linac



Assume foil size is 25 mm x 25 mm.

Beam size must be ~25 mm because no flat top in the graph of H+/H- ratio.



Why the beam is so wide?

1 p mm mrad (90%, nor.) -> 4.3 mm@beta=3 m
dp/p=0.0015 (90%) -> 1 mm@beta=0.54 m

1) dp/p is 10 times larger, 2) dispersion is larger.
3) trans. emittance is larger.

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Consistent with Suzie's measurement:

Emittance estimate (RF OUT)

[Data: 20131113_2]

$$\varepsilon = \frac{x^2}{\beta}$$

Turn 1: Δr<5mm

Turn 6, 11, 16: Δr~25mm

Turn 1: $\varepsilon \approx \frac{1}{\beta}\left(\frac{\Delta r}{2}\right)^2$

After 'smearing out' of n turns: $\varepsilon \approx \frac{1}{\beta}(\Delta r)^2$

Turn 1:
Assuming β=1.0m, Δr= 5mm = 0.005m
ε_x = 6.25 pi mm mrad

Turn 6, 11, 16:
Assuming β=1.0m, Δr= 25mm = 0.025m
ε_x = 625 pi.mm.mrad -> 100-fold increase in 5 turns!?
(NB. not accounting for dispersion, momentum spread)
If you assume this is **$\varepsilon_{100\%}$** then **ε_{RMS}** = (1/6)***$\varepsilon_{100\%}$**

TO DO: same analysis for other probes & with RF), also same analysis after attempt to fix injection angle/position.

We may see tumbling by looking at the beam at several locations.

However, optics may be mismatched at injection.